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(71) Applicant: THE UNITED STATES OF AMERICA, represented by THE SECRETARY OF THE DEPARTMENT OF HEALTH AND HUMAN SERVICES [US/US]; Box OTT, Bethesda, MD 20892 (US).

(72) Inventor: LENARDO, Michael, J.; 9117 Falls Chapel Way, Potomac, MD 20854-2453 (US).

(74) Agents: BASTIAN, Kevin, L. et al.; Townsend and Townsend Khourie and Crew, Steuart Street Tower, 20th floor, One Market Plaza, San Francisco, CA 94105 (US).

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(57) Abstract

A method for the treatment or prevention of autoimmune diseases, allergic or atopic disorders, and graft rejection is provided, comprising inducing the death by apoptosis of a subpopulation of T lymphocytes that is capable of causing such diseases, while leaving substantially unaffected the majority of other T lymphocytes. Cell death is achieved by cycle(s) comprising challenging via immunization these T cells with antigenic substance at short time intervals, or by immunization followed by administering interleukin-2 (IL-2) when these T cells are expressing high levels of IL-2 receptor so as to cause these T cells to undergo apoptosis upon re-immunization with the antigenic peptide or protein. These methods are applicable to the treatment of autoimmune diseases such as, for example, multiple sclerosis, uveitis, arthritis, Type I insulin-dependent diabetes, Hashimoto's thyroiditis, Grave's thyroiditis, autoimmune myocarditis, etc., allergic disorders such as hay fever, extrinsic asthma, or insect bite and sting allergies, food and drug allergies, as well as for the treatment or prevention of graft rejection.

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INTERLEUKIN-2 STIMULATED T LYMPHOCYTE CELL DEATH FOR THE TREATMENT OF AUTOIMMUNE DISEASES, ALLERGIC DISORDERS, AND GRAFT REJECTION

BACKGROUND OF THE INVENTION

Field of the Invention

The present invention relates to the treatment and prevention of diseases that are primarily due to T cell immune responses. In particular, it relates to the suppression or elimination of certain autoimmune diseases, graft rejection, and allergic disorders by treatment with interleukin-2 (IL-2) and the specific antigen involved, thus allowing the killing of the subpopulation of T cells that recognizes this specific antigen. In this manner, IL-2 pretreatment sensitizes T cells to undergo programmed cell death following T cell receptor engagement.

Description of Related Art

Stimulation of the $\alpha\beta$ antigen receptor of mature T lymphocytes can lead to either proliferation or programmed cell death (1-4). Programmed cell death, termed apoptosis, is one mechanism for the clonal deletion of both thymocytes and mature T cells that establishes tolerance (5-9). A minor population (approximately 5%) of T lymphocytes of unknown function, termed $\gamma\delta$ cells, has been shown to undergo apoptosis following IL-2 treatment and antigenic stimulation (28). The role of apoptosis in the normal immune response, and the mechanism by which a mature T cell selects between proliferation and death, were not previously understood.

SUMMARY OF THE INVENTION

The present invention arose from the discovery that IL-2 programs mature T cells for antigen-driven death. The T cell death caused by IL-2 followed by antigen stimulation has the hallmarks, such as DNA fragmentation and sensitivity to cyclosporin A, of "programmed cell death" or apoptosis. Thus, IL-2 acts as a death cytokine that will cause the demise only of T c lls that are specifically stimulated through their

antigen receptor. This novel use of a previously undiscovered property of IL-2 will allow the specific elimination of certain classes of antigen receptor-bearing T cells, forming the basis for new clinical applications of IL-2.

A determinant of the choice between T lymphocyte proliferation or programmed cell death is the prior exposure of these cells to interleukin-2 (IL-2). Antigen receptor stimulation in T cells not exposed to IL-2 causes normal activation, leading to IL-2 production and growth. In contrast, both $CD4^+$ and $CD8^+$ cells previously exposed to IL-2 undergo apoptosis after antigen receptor stimulation. Therefore, antigen-activated T cells that are under the influence of IL-2 will respond to rechallenge by antigen by undergoing apoptosis. The timing is significant because later antigenic stimulation after the cells are no longer under the influence of IL-2 will cause growth rather than apoptosis. Antibody blockage of IL-2 but not IL-4 reverses the rapid and drastic reduction of lymph node $V\beta8^+$ cells caused in mice by the bacterial superantigen Staphylococcus bureus enterotoxin B. Thus, IL-2 may participate in a feedback regulatory mechanism by predisposing mature T lymphocytes to apoptosis.

At least three uses for IL-2 are made possible based on this discovery. First, there is an emerging set of findings that show that infusion of peptides derived from antigens involved in autoimmune diseases leads to a reduction in severity of such diseases (cf. 73). A variety of studies of the autoimmune disease experimental allergic encephalitis (EAE) shows that it is caused by the activation of T cells upon immunization with myelin basic protein (MBP). Interestingly, infusion of peptides derived from the MBP sequence that stimulate the T cells that generate the disease are effective at blocking the disease (60). The discovery disclosed herein provides an explanation for these seemingly paradoxical observations, which is that the T cells are activated and stimulated by IL-2 during peptide infusion, and then undergo apoptosis when they are restimulated by the MBP antigen. Human diseases that have been associated with T cell activation by peptide antigens include multiple sclerosis and

autoimmune uveitis (67; 69; 107). It is envisioned that th s diseases, and, for example, systemic lupus erythematosus, systemic vasculitis, polymyositisdermatomyositis, systemic sclerosis (scleroderma), Sjogren's Syndrome, ankylosing spondylitis and related spondyloarthropathies, rheumatic fever, hypersensitivity pneumonitis, allergic bronchopulmonary aspergillosis, inorganic dust pneumoconioses, sarcoidosis, autoimmune hemolytic anemia, immunological platelet disorders, cryopathies such as cryofibrinogenemia, autoimmune polyendocrinopathies, and myasthenia gravis can be approached by therapy which can now be modulated in a rationale way using IL-2 and the relevant peptide to cause apoptosis of the T cells responsible for the disease. The appropriate timing of IL-2 infusion or a repetitive immunization schedule could substantially augment the protective effect of the infused peptides.

Secondly, there is a significant body of literature that suggests that pre-immunization of an animal or man prior to engraftment with a foreign tissue prolongs the survival time of the graft (cf. 108). One example of this phenomenon is the "donor transfusion effect," in which transfusing a patient about to receive an organ transplant with blood from the organ donor decreases rejection of the transplant. It is shown herein that CD8 cells are quite susceptible to IL-2-mediated apoptosis, and this is the primary class of T cells involved in graft rejection. Based on the discovery of this novel property of IL-2, CD8+ T cells may be induced to undergo IL-2-mediated apoptosis; administering IL-2 during and immediately after the preimmunization/transfusion phase, or repetitive immunization with MHC antigen at appropriately short intervals, could augment T cell death, leading to greater tolerance of grafts.

Thirdly, a wide variety of atopic or allergic disorders, commonly known as asthma or allergies, results from the effects of activating T cells, which causes both the release of harmful lymphokines and the production of IgE by B cells (100, 101). Over th past few decades, clinicians have made primitive attempts t treat these diseases by a

"desensitization" process consisting of repetitive exposure to the same antigen that elicited the allergy (102). Despite the fact that very little is known about the mechanisms set in play by this procedure, in some cases such treatments were highly successful (102). An important scientific by-product of this work in clinical allergy is that considerable effort has gone into identifying proteins and other molecules that cause allergic responses (100). This has led to the identification of protein sequences for antigens such as Amb a V and Amb t V, which are ragweed allergens that cause hay fever, the protein sequence and characterization of antigenic peptides from allergen M that causes allergy to codfish (105), and the molecular cloning of the cDNA for antigen 5 of white-face hornet venom, associated with allergy to hornet stings (103). Drugs that can cause allergy are typically small organic molecules that may become immunogenic by forming covalent complexes with host proteins. In addition, a large variety of allergens have been prepared as protein extracts to be administered clinically to humans under the supervision of the Food and Drug Administration, and evaluated by a Panel on Review of Allergenic Extracts (102). With the molecular identification of these and other allergy-evoking antigens, it will be possible to immunize in cycle with IL-2 to induce apoptosis of T cells involved in allergic disorders such as allergic rhinitis, bronchial asthma, anaphylactic syndrome, urticaria, angioedema, atopic dermatitis, allergic contact dermatitis, erythema nodosum, erythema multiforme, Stevens-Johnson Syndrome, cutaneous necrotizing venulitis, and bullous skin diseases.

The key feature of each of these treatment protocols is that only the antigen-specific T cells which are a small component of the patient's T cell repertoire would be eliminated. The treatment would leave the patient's immune system largely intact. This is in contrast to present treatments that rely upon general immunosuppression that seriously incapacitates the host's immune function (see 109). Moreover, because this treatment causes death of the T lymphocytes, it is superior to other recently discovered

mechanisms which do not kill T cells but rather cause functional inactivation or anergy which is typically reversible (98, 99). The experimental results described below therefore have broad clinical significance in applications to human immunological diseases.

Throughout the history of immunological approaches to human and animal diseases, beginning with the first vaccination against smallpox carried out by Edward Jenner in 1798, the emphasis has been on stimulating a positive and protective antigen-specific immune response. In modern immunology, this is known to be due to activating lymphocytes. Hence, causing the activation and proliferation of antigen-specific immune cells, especially T lymphocytes, forms the basis of most of the clinical applications of immunology. In particular, the recent advent of molecularly cloned cytokines, especially those with the ability to cause the proliferation of immune cells, has furthered the clinical application of immunology. Such molecularly cloned cytokines can be readily prepared pharmacologically, and are powerful agents for stimulating the growth and division of lymphocytes. The conceptual and practical advance offered by the discovery disclosed herein is that cytokines such as IL-2, when given in sufficient quantity, also stimulate negative regulatory effects such as T cell apoptosis. These regulatory effects represent built-in mechanisms to limit or suppress the immune response. Thus, the recognition that these mechanisms exist, and the identification of a biologic, IL-2, that potently evokes antigen-specific T cell death, offers the opportunity to exploit the negative regulation of the immune response for the treatment of disease.

Accordingly, it is an object of the present invention to provide a method for treating or preventing a disease in a human or animal caused by antigen-activated T cells, comprising inducing the death by apoptosis of a subpopulation of T lymphocytes that is capable of causing said disease to an extent greater than that of other T lymphocytes. Said disease can include an autoimmune disease, graft rejection, or an allergic or atopic disorder, and said

apopt sis can be achieved by exploiting endogenous IL2, or by administering this substance exogenously. When IL-2 is administered exogenously, apoptosis can be achieved by a cycle comprising challenging via immunization said T cells with a substance selected from the group consisting of an antigen, a peptide, a protein, a polysaccharide, an organic molecule, and a nucleic acid, followed by administering a high dose of IL-2 when said T cells are expressing high levels of IL-2 receptor, so as to cause said T cells to undergo apoptosis upon reimmunization with said substance. When endogenous IL-2 is employed to achieve apoptosis, said cycle comprises challenging via immunization said T cells by repeated administration of said substance at intervals appropriate to cause apoptosis without the subsequent administration of a high dose of IL-2, relying instead on endogenous levels of IL-2.

Further scope of the applicability of the present invention will become apparent from the detailed description and drawings provided below. However, it should be understood that the detailed description and specific examples, while indicating preferred embodiments of the invention, are given by way of illustration only, since various changes and modifications within the spirit and scope of the invention will become apparent to those skilled in the art from this detailed description.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and other objects, features, and advantages of the present invention will be better understood from the following detailed descriptions taken in conjunction with the accompanying drawings, all of which are given by way of illustration only, and are not limitative of the present invention, in which:

Fig. 1 shows apoptosis resulting from antigen or anti-CDϵ stimulation of A.E7 T cells after IL-2 pretreatment. (A) Photomicrographs of A.E7 T cells pretreated with 100 units of IL-2, then stimulated and stained with trypan blue. (Top panels) Representative fields of A.E7 T cells (small round

cells) and DCEK APCs (large fibroblastic cells) either with no antigen (left) or 1 μM pigeon cyt chrom C p ptide antigen (right). In addition to T cell death, antigen activation of A.E7 cells leads to the production of factors that cause lysis of DCEK APCS. (Bottom panels) Representative fields of A.E7 T cells in either untreated wells (lower left) or wells pre-coated with 10 μg/ml anti-CD3ϵ (lower right). Some non-adherent dead T cells and cell fragments, but not live cells, are washed away during the staining. Dark cells are cells that have died. (B) DNA prepared from equivalent numbers of A.E7 T cells was subjected to agarose gel electrophoresis and ethidium bromide staining. Lanes are from cells treated as in (A) with IL-2 and/or anti-CDϵ (145-2C11) as indicated. End lanes (M) contain pBR322/Msp I DNA markers.

Fig. 2. shows IL-2 dependent clonal elimination of Vβ8 T cells by immunization with SEB. Histograms of flow cytometry analysis of lymph node T cells taken from mice that were either uninjected (Control), injected with SEB (SEB), injected with SEB and the MAb 3C7 that blocks the binding of IL-2 to the IL-2 receptor α chain (SEB + anti-IL-2R), or injected with SEB and the MAb 11b11 that blocks IL-4 (SEB + anti-IL4).

Fig. 3 shows the decrease in human T cell number when given IL-2 followed by stimulation through the T cell receptor CD3 polypeptide using the monoclonal antibody OKT3.

Fig. 4 summarizes the therapeutic protocol for the induction of apoptosis of the present invention.

Fig. 5 shows the time course of expression of the IL-2 receptor on human peripheral blood T cells after stimulation with various antigens.

Fig. 6 shows results of experiments in which the non-transformed, CD4+ T_H1 T lymphocyte clone A-E7 was stimulated with increasing concentrations of its cognate peptide -- pigeon cytochrome c amino acids 81-104.

Figs. 7A-7C are photomicrographs showing death of T lymphocytes treated at high antigen doses.

Fig. 8 shows d cr as d T cell number quantitatively accounts for the suppression of ^{3}HTdR cpm using a FACS

viability assay. Panel a. is a representative experiment in which CD4+ cells are analyzed for the presence of Vα11 T cell receptor.

Fig. 9 shows that endogenous production of IL-2 is necessary and sufficient for antigen specific T cell death as determined using the FACS viability assay.

Fig. 10 shows the protocol for induction and treatment of EAE.

Fig. 11 shows the results from experiments using repetitive injections of MBP and IL-2 to prevent EAE.

Fig. 12 shows that repetitive injections of 400μg MBP can prevent progression of early stage EAE.

Fig. 13 shows that repetitive injections of 400μg MBP blocks relapses of EAE, thus demonstrating the effectiveness of this therapy to ameliorate existing disease.

Fig. 14 shows FACS results demonstrating that repetitive doses of MBP delete DiI stained cells.

Fig. 15 presents the results of experiments showing that repetitive doses of MBP antigen delete MBP transgenic lymphocytes in vivo.

Fig. 16 shows the protocol for therapy of EAU.

Fig. 17 shows the results of therpy of EAU as measured by scoring of EAU by ocular histopathology.

Fig. 18 shows the schedule of immunization and treatment in the production of serum IgE in response to chicken egg albumin.

Fig. 19 shows the measurement of serum IgE to determine the degree of allergic response in mice.

Fig. 20 shows flow cytometry analysis of human T cells isolated from a patient diagnosed with multiple sclerosis that are specifically reactive with myelin basic protein which were deleted using the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

The disclosures of each of the references cited in the present application are herein incorporated by reference in their entirety.

The following detailed description of the invention is provided to aid those skilled in th art in practicing the

same. Even so, the following detailed description should not be construed to unduly limit the present invention, as modifications and variations in the embodiments herein discussed may be made by those of ordinary skill in the art without departing from the spirit or scope of the present inventive discovery.

Therapeutic Applications in Human and Veterinary Medicine

I. General Principles

The discovery that interleukin-2 (IL-2) predisposes T lymphocytes to programmed cell death, or apoptosis, allows for a novel method of therapeutic intervention in disease processes in humans and animals primarily caused by the action of T cells (30). In essence, this involves specifically inducing the death of a subpopulation of T lymphocytes that are capable of causing disease, while leaving the majority of T lymphocytes substantially unaffected. This method of intervention contrasts with, and is potentially far superior to, currently used therapeutic methods that cause a general suppression or death of T lymphocytes. Examples of widely-used general immunosuppressive agents are corticosteroids, such as preunisone, which are used to treat autoimmune diseases and allergic conditions, and cyclosporin A, which is used for treating graft rejection (31). These treatments suffer from the drawback of severely compromising immune defenses, leaving the patient vulnerable to infectious diseases. The two key elements of the present process are that: i) only the subset of T cells that reacts with antigens that cause the disease are affected by the treatment; and ii) the T cells affected by the treatment are killed, i.e., they are permanently removed from the repertoire.

Several general principles underlie the present process. T cells recognize antigen in the form of short peptides that form noncovalent complexes with major histo compatibility complex (MHC) proteins on the surface of antigen-presenting cells found throughout the body (32). Antigens may also take the form f polysaccharid s, rganic

molecules, or nucleic acids. Each T cell bears a unique receptor called th T cell recept r (TCR) that is capable of recognizing a specific antigen-MHC complex. Through rearrangement of the gene segments containing the protein-coding segments of the TCR, a vast array, perhaps a virtually unlimited number of combinations, of different TCRs are generated (33). By a mechanism termed "allelic exclusion", each T cell bears a single unique TCR. The T cell repertoire is therefore a large number of T cells, each with a distinct TCR that recognizes a specific antigen-MHC complex. It is this vast array of T cells that allows immunological responses to the diversity of antigenic structures on invading microorganisms, tumor cells, and allografts, thus preserving the integrity of the organism.

Most antigens are able to elicit a response in only a very tiny fraction of the T cell repertoire (34). For example, the initial response to protein antigens may involve as few as 1/1000 to 1/10,000 T lymphocytes (35). For this reason, diseases caused by T cell reactivity are mediated by only a small subset of the large repertoire of T cells (36). In particular, in those cases where it has been directly measured, such as in multiple sclerosis, the fraction of the T cell repertoire which mediates disease is quite small (36). The important feature of the T cell subset that participates in disease is that it involves T cells which specifically recognize an antigen that provokes the disease. In allergic conditions, the antigen causes the release of inflammatory response molecules. In autoimmune diseases, the antigen may be derived from a specific organ in the body and, when recognized by a subset of T cells, stimulates the T cells to attack that organ. A similar effect occurs during graft rejection. Antigenic proteins in the transplanted organ evoke a response in a subset of T cells that attacks the engrafted tissue. For unknown reasons, the fraction of T cells recognizing foreign or "allo" tissue is significantly higher than the number that will typically recognize a protein antigen. N netheless, th number of responding T cells is

still a distinct minority (1-10%) of the ov rall T cell repertoire (37).

In a typical response to a specific antigen-MHC complex, the T cells undergo a cascade of gene activation events that results from stimulation of the TCR (38). These have been extensively characterized at the molecular level, and two such activation events are especially germane to the present therapy: production of the lymphokine IL-2, and, expression of the cell surface proteins that constitute high-affinity receptors for IL-2. IL-2 is a 15,000 dalton protein that causes T cells bearing the appropriate high affinity receptor to divide (68). Non-activated T cells do not express high affinity IL-2 receptors (39). The production of IL-2 followed by its interaction with its receptor causes an autocrine mechanism that drives the T cells into the cell cycle (39). This leads to an initial expansion of T cells that are specifically reactive with the antigen. The present inventive discovery indicates that IL-2 also has the surprising effect of predisposing the expanded pool of either human or mouse T cells to apoptosis or programmed cell death if they are again stimulated or rechallenged through the TCR (30, 74). In the present work described <u>supra</u>, the degree of apoptosis achieved in either human or mouse T cells is correlated positively with both the level of IL-2 the cells experience during their initial expansion, the strength of the TCR stimulation upon rechallenge, and the timing of the rechallenge. The effects of IL-2 wear off 2-3 days after IL-2 is no longer present, hence rechallenge must occur within that period (94). The process of activation and apoptosis eventually depletes the antigen-reactive subset of the T cell repertoire. Apoptosis denotes a type of programmed cell death in which the T cell nucleus shrinks, the genetic material (DNA) progressively degrades, and the cell collapses (1, 40). Evidence would suggest that cells cannot recover from apoptosis, and that it results in irreversible killing (1, 40). T cells that do not undergo apoptosis but which have b come activated will carry out their "effector" functions by causing cytolysis, or by secreting lymphokines that cause B

cell responses or other immune effects (41). These "effector" functions are the cause of tissue damage in autoimmune and allergic diseases or graft rejection. A powerful approach to avoiding disease would therefore be to permanently eliminate by apoptosis only those T cells reactive with the disease-inciting antigens, while leaving the majority of the T cell repertoire intact.

By using IL-2 as an agent that predisposes T cells to death by TCR stimulation in appropriate cycle with immunization with the antigen(s) leading to autoimmune disease or graft rejection, the death of disease-causing T cells can be invoked. Specific methods are described for i) treatment of autoimmune or allergic diseases by identified protein antigen and IL-2, and ii) treatment of graft rejection by blood cell antigens and IL-2. Such methods, by logical extension, can be further developed for other diseases of man or animals that result from the effects of T cells activated by specific antigens. Because the vast majority of immune responses depend on T cell activation, whether cytotoxic responses or antibody production are involved, it is predicted that this form of therapy could be applied to a wide variety of autoimmune and allergic conditions (100, 106).

II. Method for IL-2/peptide-mediated apoptosis of T lymphocytes.

In several human autoimmune diseases, data have indicated that antigen-activated T cells play a key role in the production of disease. These include but are not limited to: 1) multiple sclerosis (42-47); 2)uveitis (48, 49)) ; 3) arthritis (50-52) ; 4) Type I (insulin-dependent) diabetes (53, 54); 5) Hashimoto's and Grave' s thyroiditis (55-57) ; and 6) autoimmune myocartiditis (58). The ethical limits on human experimentation have made it very difficult to prove that T reactivity is the sole inciting agent of these diseases. Nonetheless, a large body of experimental work on animal models -- murine experimental allergic encephalitis as a model for multiple sclerosis (59, 60), BB diabetic rats for human diabetes (61, 62), murine collagen-induced arthritis for

rheumatoid arthritis (63, 64), and S antigen disease in rats and guinea pigs for human autoimmune uveitis (65, 66), among others -- suggests that T cells are the critical agent of these diseases. From recent work, the identity of disease-causing proteins or peptide antigens is emerging: i) multiple sclerosis: the peptide epitopes of myelin basic protein (MBP) residues 84-102 and 143-168 (45, 66, 67); ii) autoimmune uveitis: the human S antigen, which has been recently molecularly cloned (48, 69) ; iii) type II collagen in rheumatoid arthritis (70); and iv) thyroglobulin in thyroiditis (71). Similarly, a wide variety of proteins have been identified which stimulate the production of the allergic immunoglobulin, IgE. IgE is produced by β lymphocytes in a process that requires lymphokines produced by antigen-activated T cells known as "T cell help."

The basic concept of the present therapeutic approach is very simple. Disease-causing T cells are first challenged by immunization, which causes the activated T cells to express high affinity IL-2 receptors and to begin producing and secreting IL-2. When the cells are expressing high levels of IL-2 receptor, additional human IL-2 is infused to very efficiently drive all the activated cells into cycle. The cells under the influence of IL-2 are then caused to undergo apoptosis by re-immunization with antigenic peptide or protein. Further, if the antigen is capable of stimulating sufficient IL-2 production, it is not necessary to administer exogenous IL-2. In either case, the timing of rechallenge is important -- it must occur within a short interval such as 2-3 days after the first stimulus when cells bear the IL-2 receptor and are responding to exogenous or endogenous IL-2.

<u>Protocol</u>:

As shown in Figure 4, immunization with a specific peptide or protein is carried out on day one. In the case of multiple sclerosis, for example, either of two immunodominant peptides from myelin basic protein (MBP) believed to be encephalitogenic in man, MBP 84-102 (the preferred peptide), or MBP 143-168 (66-68), that have been coupled to tetanus toxoid, can b given in alum adjuvant IM, at a dose betw en

about 10 t about 1000 μg. Previous experi nce using proteins or peptides has suggested that intramuscular (IM) administration is optimal (85-87, 89, 90). New r data suggest that oral administration may also be effective (73).

As with any medicinal substance, or biologic, tests on any peptides and proteins used for the immunization would need to be routinely carried out over a range of doses to determine: 1) the pharmacokinetic behavior of these substances; 2) their immunogenicity; and 3) safety and identification of any untoward effects. This would constitute a Phase I clinical trial (84). Thus, the particular proteins or peptides employed in this protocol (for example, in multiple sclerosis, MBP 84-102, or MBP 143-168; in uveitis, the S Antigen; or in rheumatoid arthritis, type II collagen) would require individual routine optimization. Similar intervention could be used with preparations of allergy-inducing proteins. These could be derived from a variety of allergen protein extracts that are now used clinically, or could be generated by recombinant DNA technology for those such as hornet venom antigen 5, for which cDNA clones are available (103). Ample evidence from the development of vaccines suggests that either synthetic peptides or recombinant DNA-derived proteins are effective in eliciting an immune response in humans (85-90). These studies also provide guidance as to the range of doses effective for immunization.

<u>Proteins</u>:

1) Hepatitis B surface antigen, produced as a recombinant protein in yeast. Adults 2.5 to 20 μg; children 1.25 to 5 μg intramuscularly (IM). 90-96% of vaccines showed an immune response, with the best response at 10-20 μg (85). Further studies showed the efficacy of a 10 μg dose, with better results when given IM rather than subcutaneously (86). 20 μg doses in alum adjuvant given IM were found to be effective at preventing infection in clinical trials (87).

2) HIV gp 120, either natural or recombinant molecules. Dos s in chimpanzees between 50-1000 μg elicit T cell responses (88).

Peptides:

1) Chorionic gonadotropin. Several studies have indicated successful immune responses against a human chorionic gonadotropin-β subunit peptide (residues 109-145) coupled to cholera or tetanus toxoid and given in doses from 50-1000 μg in alum adjuvant (89).

2) Malaria sporozoite antigen. Studies of a Plasmodium falciparum peptide $(NANP)_3$ coupled to tetanus toxoid showed an immune response to doses of 20-160 μg of peptide conjugate given IM, with the best response at 160 μg (90).

Immunization is then followed by a waiting period during which the antigen activates the subset of T cells bearing reactive TCRs, causing them to express IL-2 and IL-2 receptors. This process will only induce IL-2 receptors on cells that have been antigenically-stimulated (39). Based on studies of both human and mouse T cells in vitro, between about 12 to about 24 hours after antigen exposure are required to express significant numbers of IL-2 receptors, and as long as about 72 hours are required to express optimal numbers of IL-2 receptors on the majority of T cells (74; Figure 5). Thus, the waiting period can be as short as about 12 hours or as long as about 72 hours, becoming increasingly optimal toward the upper end of this range.

Figure 5: Human peripheral T lymphocytes were stimulated with either 5 μg/ml concanavalin A or 1 μg/ml phytohemagglutinin for various time periods. The cells were then harvested, washed and stained with FITC-labelled anti-IL-2Rα MAb specific for the human protein (anti-Tac). Flow cytometry was carried out on a Becton-Dickinson FACSCAN cytometer and analyzed using the Lysis II software.

This is then followed by an infusion of high doses of IL-2. The administration of high-dose IL-2 to humans has been well-studied in cancer patients, and various doses have been evaluated (75-79). A number of ongoing protocols evaluating the medical uses of IL-2 presently exist (95). Data indicate that IL-2 should be given I.V., either as frequ nt bolus doses or as a continuous infusion (75-77).

Doses that have been previously established range between about 300 t about 3000 units/kg/hour continuous infusion, or from 10^4 to 10^6 units/kg I.V. b lus (76). Units are defined by standards available from the Biological Response Modifiers Program at the National Institutes of Health, and are defined as the quantity of IL-2 that gave 50% maximal thymidine incorporation in the bioassay under standard conditions. Side effects of these doses included chills, fever, malaise, headache, nausea and vomiting, weight gain due to fluid retention, diarrhea, rash, and pruritis, which can all be treated with acetaminophen or indomethacin; no serious morbidity or mortality was observed. Despite the apparent short half-life of IL-2 in serum, at a dose of 3000 u/kg/hr, IL-2 was detected in patient serum at a level of 5-10 units/ml. These levels have been found to predispose on the order of 60-70% of the T cells to apoptosis, <u>supra</u>. IL-2 infusion can be continued for about 48 to about 72 hours, a time frame shown to ensure that IL-2 receptor bearing cells are stimulated into the cell cycle and predisposed to apoptosis (<u>supra</u>, and 74). A 48-72 hour treatment should avoid the serious complication of excessive fluid retention even at high doses of IL-2 (76). After IL-2 treatment, the patient can be immediately reimmunized with an equivalent dose of antigen. For example, for multiple sclerosis, treatment can be with about 10 to about 1000 μg of peptide 84-102 coupled to tetanus toxoid and given in alum adjuvant IM. It is likely that the preferred dose would be near the upper end of this range since greater TCR stimulation produces a greater level of apoptosis (94). IL-2 treatment would have stimulated the T cells bearing IL-2 receptors -- predominantly the disease-causing T cells -- and these cells would then be re-stimulated through their TCR. These cells will then undergo apoptosis (<u>supra</u>, 74). After an immunization period of about 12 to about 72 hours, the cycle would begin again with reinfusion of IL-2. As will be described below, increased efficacy would likely result from multiple cycles of th rapy. The treatment endpoints w uld be: i) elimination of <u>in vitro</u> reactivity to the antigen, which can be easily

measured where possible by various mixed lymphocyte or proliferation assays using peripheral blood lymphocytes; ii) amelioration of clinical symptoms; or iii) toxicity. The treatment endpoints for allergic diseases would be: i) improvement of clinical symptoms; ii) normalization of an allergic skin test; iii) reduction in serum IgE levels; and iv) where possible to measure, reduced T cell responses to the allergenic protein.

Several features of the present therapy require further explanation. First, it is expected that T cells besides those antigenically stimulated will express high affinity IL-2 receptors. Treatment with high doses of IL-2 causes expression of the high affinity IL-2 receptor in a small fraction of resting T lymphocytes (76). However, this should not diminish the specificity of the therapy because only those cells whose TCRs are stimulated by rechallenge with antigen will undergo apoptosis, as described supra. The effectiveness of the therapy could be variable depending on the nature of the antigen and the exact protocol employed. Extensive in vitro studies indicate that between 50-80% of the antigen-specific IL-2 stimulated T cells will undergo apoptosis when rechallenged by TCR stimulation (supra, 76). Second, the reduction in number of antigen-specific T cells determines the overall effectiveness of the therapy. Therefore, repeated cycles can substantially increase efficacy even if the level of killing in each cycle is only 50-70% (Table 1). As shown in the mouse studies, supra, the level of antigen-reactive T cells will decrease below the number of such cells prior to the first immunization with repetitive immunization. Furthermore, the expected toxicity of this protocol should be minor, and previous studies of the therapeutic use of IL-2 in humans indicates that all side effects dissipate promptly following the discontinuation of IL-2 (75, 76). The most serious side effect, fluid retention, should be minimized by the intermittent nature of IL-2 treatment (79). The 2-3 day rest period between doses would allow for diuresis of the fluid built up during IL-2 administration. Finally, the repeated administration of

antigen will cause production of some endogenous IL-2, which will predispose some cells to ap ptosis. While it is extremely unlikely that endogenous levels can reach the very high levels of IL-2 that can be administered pharmacologically, it is possible that empirically-determined decreases in the IL-2 dose could be achieved because of endogenous IL-2 effects. The level of killing is dependent on the total level of IL-2 to which the T cell is exposed, and this will reflect a combination of endogenous and exogenous sources (supra, 76).

With certain antigens, the pre-disposition of cells to apoptosis may be sufficiently induced by the endogenous production of IL-2. In these cases, appropriate immunization with antigen, in the absence of exogenously administered IL-2, could produce T cell apoptosis and a protective effect. Based on the studies of the timing of susceptibility to apoptosis disclosed supra, immunizations repeated at specific intervals would be crucial for effective therapy. To effect IL-2-mediated apoptosis, immunizations would have to be repeated at about 24 to about 120 hour intervals, preferably at about 24 to about 72 hour intervals, and would have to be repeated multiple times. T cell reactivity or cell-mediated immunity for the specific antigen could then be monitored by in vitro assays to determine that T cells had undergone apoptosis. Absent the knowledge provided by the discovery disclosed herein, previous attempts to decrease immune responsiveness by repetitive immunization have not been optimal. For example, donor transfusion protocols to ameliorate graft rejection involved 3 transfusions given at 2 week intervals (91, 92). Allergy shots, i.e., desensitization therapy, are typically given initially at 4-7 day intervals, after which intervals are progressively increased in length to 2 to 4 weeks (102). Based on the present novel understanding of T cell apoptosis, the most effective immunization protocol would involve repetitive administrations of antigen at about 24 to 72 hour intervals.

TABLE 1

Theoretical number of reactive cells after fractional killing using IL-2 and T cell receptor stimulation

Cells Cycle	Fractional Killing	Reactive Remaining
Start	None	100,000
1	70%	30,000
2	70%	9,000
3	70%	2,700
4	70%	810
5	70%	243
6	70%	73

Theoretical values are based on starting with 100,000 cells and a constant killing efficiency of 70%. A reduction of over 100-fold is seen in 4 cycles and over 1000-fold in 6 cycles. At a fractional killing of 50%, a reduction of nearly 100-fold would be seen in 6 cycles.

III. Method for transplantation antigen/IL-2-mediated apoptosis.

In medical procedures in which tissue is transferred between individuals who are genetically non-identical at their relevant histocompatibility antigen loci, herein referred to as allografting, and the tissue as an allograft, the major problem encountered is rejection of the donor allograft by the host. The term "host" refers to the individual who is the recipient of the allograft, and the term "donor" refers to the individual from whom the allograft is derived. Studies of the process of graft rejection have shown that it is due to the antigen-specific activation of T lymphocytes, especially those bearing CD8 surface molecules (80). More importantly, agents that block the ability of T cells to mount an immune response in humans effectively prevent or less n graft rejection (81).

Since $CD8^+$ T cells have been shown to be susceptible t apoptosis by IL-2, <u>supra</u>, this phenomenon can be used as a specific means to eliminate the reactive T cells, thereby avoiding graft rejection.

<u>Protocol</u>: Essentially the same protocol with respect to timing and IL-2 dose can be used for this therapy as was described <u>supra</u> for the therapy of autoimmune diseases. The major difference between this therapy and that described above is the source of antigen. Major histocompatibility complex (MHC) antigens are cell surface proteins that are tremendously polymorphic among individuals. Each individual's cells bear a genetically determined set, or haplotype, of such antigens which serve as an immunological "fingerprint" on each cell (82). This allows one's immune system, in particular those responses generated by T cells, to recognize one's own cells, and to attack only cells that do not bear the self "fingerprint" (83). There are two classes of MHC -- class I antigens, found on all cells in the body; and class II antigens, found predominantly on monocytes, macrophages, B lymphocytes, dendritic cells, and activated T cells (82). It is the class I MHC antigens that are recognized by $CD8^+$ T cells that are the predominant influence in allograft rejection (80, 83). Because of this complexity of MHC antigens, the simplest source is cells from the allograft donor. It has been empirically observed that transfusion of a graft recipient with donor blood suppresses graft rejection, although the mechanism of this effect is unknown, and the clinical effectiveness in many cases is modest (92). These protocols provide evidence that three transfusions of 200 ml of whole blood or packed cell equivalent from the donor is easily tolerated by the recipient with minimal side effects (91). There is evidence that the donor-transfusion in some cases elicited sensitizing antibody responses in the allograft host, and these patients were not given allografts (91). These studies possibly represent an empirical observation that pre-exposure to donor antigen suppresses the T cell response, although this is controversial (93). The present method

includes administration of blood as a source of MHC antigens in d ses of about 50 to about 200 ml to patients in cycle with IL-2, as indicated in Fig. 4. In the case of kidney transplants, the amount of blood could be determined by the fluid tolerance of end-stage renal disease patients. The blood can be given as either whole blood, packed cells, or washed packed cell transfusions (92). The success of treatment can be assessed by: i) a decreased requirement for general immunosuppressive medications; ii) graft survival; and iii) adequate function of the allograft. For example, the function of a transplanted kidney can be established by determining serum levels of creatinine and blood urea nitrogen (104). This can be followed by IL-2 infusion and rechallenge with blood cells as antigen as shown in Figure 4.

IV. Summary.

The conceptual advance provided by the inventive discovery that underlies the present methods is that T cell immunity works as a balance between the production and destruction of antigen-specific T lymphocytes. Previously, investigators have focused on the use of lymphokine growth factors such as IL-2 to increase the proliferation and responsiveness of T lymphocytes (68). It is now proposed that the opposing T cell mechanisms be used therapeutically. The discovery that IL-2 predisposes T cells to death is contrary to the previously understood properties of IL-2, and provides a radically new approach to the treatment of diseases caused by T cell reactivity. By providing physicians and medical researchers with the basis of the present inventive discovery, the processes of immune autoregulation leading to T cell destruction can be exploited in combatting disease.

It has been previously known for some time that prior activation and IL-2 production were capable of diminishing immune responsiveness both in vivo and in vitro (1-4, 95-97). The mechanism for these effects was not understood. Absent the knowledge that IL-2 predisposes T lymphocytes to antigen-dependent apoptosis, it was not possible to manipulate this ph nomen n for medical or

th rapeutic purposes. Recent results demonstrate that human T lymph cytes are quite susceptible to apoptosis following IL-2 exposure (74). It is now possible to rigorously study the kinetics and dose requirements of IL-2 in the predisposition phase, and antigen in the apoptosis phase, to routinely optimize the treatment cycle for a given disease following the guidance provided herein.

That this process depends on the discovery of a novel property of IL-2 is particularly auspicious. IL-2 is perhaps the best studied lymphokine (68). It is well-understood genetically, its cDNA and gene have been molecularly cloned, and its mRNA expression has been thoroughly studied (68). IL-2 is already available pharmaceutically in a form for use in humans (79). Previous studies in human cancer victims, detailed above, have given clear insights into how IL-2 affects human physiology at different doses (79). All of these features significantly enhance the feasibility of its novel use to cause auto-destruction of disease-causing T lymphocytes for the treatment of a wide variety of diseases in humans and other mammals.

Example 1

This example shows the effect of IL-2 on antigen response in A.E7, a non-transformed $CD4^+$ T_H1 T lymphocyte clone that constitutively expresses high affinity IL-2 receptor and produces IL-2 after antigen stimulation (10,11). Resting A.E7 cells given 1 μM antigen underwent proliferation due to endogenous IL-2 production (from 435 to 22894 CPM [^{3}H]thymidine). By contrast, A.E7 cells given 100 units/ml exogenous IL-2 for two days and then 1 μM antigen showed decreased [^{3}H]thymidine incorporation (51755 to 7140 CPM). Decreased incorporation might have been due to an antigen-dependent block in IL-2 stimulated proliferation (12,13), but microscopic examination unexpectedly revealed extensive death of the T cells (Fig. 1A, upper panels). For the IL-2 pretreated sample, quantitation revealed 82% fewer T cells following 1 μM antigen stimulation compared to control Table 2). Cell death was less dramatic with lower dos s of

IL-2, but was still evident between 2 and 5 nits/ml, at which 50-60% of the T cells were killed (Table 2). A smaller cell loss was seen in T cells given no IL-2 pre-treatment that could be attributed to IL-2 produced by antigen stimulation. These results suggested the hypothesis that IL-2 following antigen stimulation leads to proliferationt, whereas IL-2 exposure prior to antigen stimulation causes cell death.

Table 2 Effect of IL-2 and antigen receptor stiumlation on T cell viability

Cells		Pretreatment	Cell Number/well ($x10^4$) Control	$1 \mu M$ antigen	stimulated % control
A.E7	Expt 1	no IL2	3.8 ± 0.3	2.3 ± 1.8	60%
		100 units IL2	4.9 ± 2.5	0.9 ± 0.6	18%
	Expt 2	no IL2	3.6 ± 0.4	2.8 ± 0.6	78%
		2 units IL2	5.0 ± 0.4	2.4 ± 0.1	48%
		5 units IL2	6.2 ± 0.5	2.4 ± 0.4	39%
		10 units IL2	6.8 ± 0.6	2.0 ± 0.2	29%
		50 units IL2	6.8 ± 1.0	2.0 ± 0.7	29%
			Control	$10 \mu g/m$ anti-CD3ϵ	
	Expt 3	no IL2	4.3 ± 0.5	3.2 ± 0.4	74%
		2 units IL2	7.1 ± 1.5	3.6 ± 0.1	51%
		5 units IL2	6.4 ± 0.8	2.1 ± 0.6	33%
		10 units IL2	7.4 ± 1.5	1.0 ± 0.2	14%
			Anti-CD3ϵ	Anti-CD3ϵ+CsA	
	Ept 4	no IL2	3.9 ± 0.5	4.4 ± 0.5	
		25 units IL2	2.2 ± 0.5	4.2 ± 0.9	
			Control	$20 \mu g/ml$ anti-Vβ8	
LNT		3 units IL2	5.7 ± 1.1	9.1 ± 1.2	160%
		100 units IL2	39.8 ± 2.0	20.1 ± 6.4	50%
				$33 \mu g/ml$ anti-Vβ6	
		3 units IL2		9.4 ± 1.0	165%
		100 units IL2		26.8 ± 4.7	67%

Cell counts ($x10^{-4}$) are averages of 4-6 independent hemocytometer counts of three wells determining only trypan-blue excluding cells. Antigen was the 81-104 peptide from pigeon cytochrome c (a gift of B. Beverly). The anti-CD3ε antibody 145-2C11 (16) was used at the concentrations indicated, except for Expt. 4 where 2.5 μg/ml was used. Plates were coated with 20 μg/ml anti-Vβ8 (F23.1 MAb) and 33 μg/ml anti-Vβ6 MAb(RR4-7MAb) as described in the legend to Figure 1. Control experiments in which equivalent amounts of MAb recognizing CD4, MHC class I, or CD45 were coated on plates had no effect on cell viability (data not shown). Cells were incubated in dishes for 48 hours. Trypan blue stained cells (blue) made up 30-70% of the differences between stimulated and controls where quantitated. Cyclosporin A (CsA, a gift from Sandoz Pharmaceuticals, Inc.) was included at 100 ng/ml only during the stimulation by 145-2C11 antibody. IL-2 was human recombinant IL-2 (provided by Dr. Craig Reynolds, Biological Response Modifiers Program, NCI) or supernatant from MLA-144 cells (provided by the Fermentation Laboratory, FCRF, NCI), both of which gave essentially identical results. Data are representative of 8 experiments.

To test this idea, IL-2 and antigen stimulation were evaluated in an experiment in which endogenous IL-2 was not produced. A.E7 cells (and other $CD4^+$ T_H1 T cell clones) require a co-stimulatory signal from antigen-presenting cells (APCs) in addition to occupancy of the T cell receptor complex to produce IL-2 (14,15). Therefore, in the absence of APCs, A.E7 cells were pre-treated with IL-2, washed, and stimulated on culture dishes coated with a monoclonal antibody (MAb) to CD3ε complex (16). This resulted in almost no endogenous IL-2 production (data not shown). Nonetheless, IL-2 pre-treatment followed by anti-CD3ε stimulation again led to extensive T cell death (Fig. 1A, lower panels). Quantitation showed that 74% of the untreated cells, but only 14% of the T cells pre-treated with 10 units/ml of IL-2, were recovered alive (Table 2). As was observed with antigen stimulation, killing caused by anti-CD3ε was dependent on the IL-2 dose, with 49% cell loss at 2 units/ml. Dying A.E7 cells exhibited a pattern of DNA fragmentation to 200 bp nucleosome-length multipl s after IL-2 and anti CD3ε stimulation (Fig. 1B, 2C11). Also, cell

death was abrogated by cycl sporin A (Table 2, CsA). Together, these data strongly suggested that apopt sis was occurring (1,2,5,7).

It was then tested whether IL-2 could predispose cells bearing particular T-cell receptors (and not bystander cells) to apoptosis in a heterogeneous lymph node T (LNT) cell population. Because LNT cells do not constitutively express IL-2 receptors, they were first stimulated with the lectin concanavalin A. This caused the cells to express the IL-2 receptors and become IL-2-responsive (data not shown). The concanavalin A was then removed and the cells were exposed to IL-2. Since LNT cells did not survive without any IL-2, low dose (3 units/ml) and high dose (100 units/ml) IL-2 were compared. IL-2 was given for two days and the LNT cells (>97% $\alpha\beta$ T cells, data not shown) were plated on dishes coated with either no antibody, the F23.1 monoclonal antibody (MAb) (anti-Vβ8, specific for the Vβ8.1,2,3 receptor chains) (17), or the RR4-7 MAb (anti-Vβ6) (18). In low IL-2, both anti-Vβ8 and anti-Vβ6 MAbs caused the cell number to increase (Table 2). After high IL-2, anti-Vβ8 caused nearly 50% cell loss, and anti-Vβ6 led to a 33% cell loss (Table 2) . Flow cytometry revealed that anti-Vβ8 MAb markedly deleted cells with cognate Vβ8 receptors in LNT cells given high IL-2 but not in LNT cells given low IL-2 (data not shown). To accurately quantitate the deletion observed with high dose IL-2, the populations were gated separately into CD4$^+$ cells and CD4$^-$ cells (virtually all CD8$^+$ cells, see legend)(Table 3). Anti-Vβ8 MAb decreased the fraction of Vβ8$^+$ cells from 38.4% to 14.1% for CD4$^+$ cells and from 38.0% to 19.4% for CD4$^-$(CD8) cells but had no effect on Vβ6$^+$ cells, which were relatively increased to compensate for the loss of Vβ8$^+$ cells (Table 3). Similarly, anti-Vβ6 MAb caused deletion of Vβ6$^+$ cells (from 12.3% to 1% for CD4$^+$ cells and from 10.0% to 2.2% for CD4$^-$ (CD8) cells), but not Vβ8$^+$ cells, which were relatively increased (Table 3). These findings were not due to T cell receptor down-modulation because: 1) substantial apoptosis and decreased cell number were observed; 2) c lls bearing heterologous receptors were relatively increased; and 3) no T

cell receptor negative cells were detected (data not shown). Thus, IL-2 predisposes to an endogenous death pathway in both $CD4^+$ and $CD8^+$ T cells. Bystander cells, though competent to undergo apoptosis, are not affected by antigen-receptor-mediated killing of a subpopulation of LNT cells.

TABLE 3 Flow cytometric quantitation of in vitro deletion of Vβ8- and Vβ6-bearing LNT cells using anti-receptor antibodies

Gating	Fraction of total gated cells positive for:	Stimulation after LI-2 pre-treatment None	Anti-Vβ8	Anti-Vβ6
CD4+cells	Vβ8	38.4%	14.1%	3%
	Vβ6	12.3%	15.9%	1.0%
CD4-(CD8) cells	Vβ8	38.0%	19.4%	40.6%
	Vβ6	10.0%	16.4%	2.5%

Lymph node T cells pre-treated with 100 units/Ml IL2 were prepared as described in Fig. 2 and stimulated on culture dishes coated with either no antibody or MAb against either Vβ8 (F23.1) or Vβ6(RR47). Cells recovered from the plates were stained for two color cytometry with both anti-CD4 (Becton Dickinson) and either anti-Vβ8(F23.1) or anti-Vβ6 (RR4-7). The CD4 staining was used to gate the cells into $CD4^+$ and $CD4^-$ pools; control staining showed that virtually all $CD4^-$ cells were $CD8^+$ (using anti-Lyt2), and cells were >97% αβ T cells (using H57-597) in these preparations. The gated pools were then quantitated by flow cytometry using a Becton Dickinson FACSCAN for the fraction of either $V\beta8^+$ or $V\beta6^+$ cells. Independent gating was necessary for accurate quantitation because of the previously described overgrowth of CDB cells in antibody stimulated samples (29). The fraction of the gated pool that was positive for either Vβ8 or Vβ6 is given as percent; boxed values show Conditions where deletion was bserv d. The data are repr sentative of 5 experiments.

The hypothesis that IL-2 preceding antigen receptor occupancy leads to apoptosis predicted that repetitive immunization could eliminate antigenspecific T cell clones <u>in vivo</u>. Furthermore, such elimination would depend on IL-2 produced by activated T cells predisposing themselves and their progeny to death. To test this prediction, BALB/c mice were given <u>Staphylococcus</u> <u>aureus</u> enterotoxin B (SEB) I.V. using a loading dose of 500 μg followed by two injections of 125 μg at two day intervals. SEB was used because it activates all T cells bearing a Vβ8 polypeptide chain in their T cell receptor. Vβ8 bearing cells comprise nearly one quarter of the repertoire of a BALB/C mouse, and therefore can be measured easily by flow cytometry. After eight days, the mice were sacrificed, and peripheral lymph node T cells were analyzed for Vβ8$^+$ cells (which are specifically activated by SEB) and Vβ6$^+$ cells (which are not stimulated by SEB) (19). Flow cytometry for representative mice is shown in Fig. 2. In an uninjected animal, 22.3% of the T cells were detected by the antibody KJ16-33 (20) which recognizes Vβ8.1,8.2 receptors. As predicted, repetitive immunization with SEB reduced the relative number of Vβ8.1,8.2$^+$ cells to 7.5%, over a 60% decrease. Injection of SEB together with 800 μg of MAb 3C7, an IL-2 receptor alpha chain blocking antibody (21,22), (anti-IL-2R, a gift of Dr. A. Kruisbeek) every 12 hours I.P. caused a striking reversal of the loss of Vβ8.1,8.2$^+$ cells to 18.1%. Co-injection of MAb 11B11 previously used to block IL-4 responses <u>in vivo</u> (22,23) (anti-IL-4, a gift of Dr. W. Paul), did not reverse the loss of Vβ8.1,8.2$^+$ cells caused by SEB (Table 3). The fractions (mean ± S.D.) of Vβ8.1,8.2$^+$ cells for several mice were similar: normal, 23.3 ± 0.6% (n=4), SEB only, 9.7 ± 2.8% (n=4), SEB + anti-IL-2R, 19.5 ± 3.8% (n=3), and SEB + anti-IL-4, 9.4 ± 1.8% (n=3). Vβ6$^+$ T cells showed no deletion in these mice. A similar blocking effect was observed using the MAb S4B6 that directly binds the IL-2 lymphokine molecule itself (data not shown). No effects on the number of Vβ8 or Vβ6 cells were seen if antibody 3C7 or 11B11 was injected without SEB (data now shown). Moreover, no evidence of Vβ8 T cell redistribution from lymph into other

tissues was found by pathological analysis (data not shown). Thus, cl nal eliminati n caus d by SEB under these conditions depends on IL-2 but not IL4.

By three different experimental protocols, a direct involvement of IL-2 in antigen-receptor driven T lymphocyte elimination was found. IL-2-induced apoptosis has the features of feedback inhibition (25) it is caused by an "end-product", e.g., IL-2, of the initial antigen stimulation; ii) apoptosis was greater with increasing doses of IL-2; and iii) it reverses the increased T cell numbers initially caused by antigen (1,4,8,9). T cell clonal specificity is maintained by the requirement for antigen stimulation as well as IL-2 for apoptosis; however, antigen receptor occupancy alone is not sufficient for apoptosis. A useful term for this feedback pathway would be "propriocidal" regulation (Latin: proprius, "one's own") to indicate selective killing of the stimulated T cells, their progeny, and clones of related specificity. One conceivable role of this pathway may be illustrated by Staphylococcal enterotoxins whose lethality seems due to substances produced by activated T cells (19,26). IL-2-mediated apoptosis could eliminate the affected T cells and decrease the harmful effects of chronic exposure to these toxins.

These results have been extended to human T lymphocytes (74). Human peripheral blood T lymphocytes were stimulated to express the high affinity IL-2 receptor using either phytohemagglutinin or concanavalin A. These cells were then stimulated with either 0, 2, or 200 units of IL-2. Proliferation and an increased cell number were observed in response to IL-2 (Fig. 3). Upon rechallenge of the cells with an antigen surrogate, namely, a MAb against a human CD3 polypeptide of the T cell receptor (OKT3), the cell numbers dropped if the cells had previously been exposed to IL-2 but not if they were untreated (Fig. 3). In samples pretreated with IL-2 and then restimulated with OKT3, ladders of fragmented DNA were also observed by agarose gel lectrophoresis, indicating that apoptosis was occurring (data n t shown). Thus, the ability of IL-2 t predispose to

apoptosis is not a peculiarity f murine T cells, but also ext nds to human T lymphocytes, and m st likely represents an intrinsic T cell regulat ry mechanism. This theref re makes it possible to exploit antigen driven T cell apoptosis for the treatment of diseases in humans, mice, and presumably mammals or other animals that have T cells with similar properties.

Figure 1: The A.E7 T cell is a non-transformed $CD4^+$ T_H1 T cell clone that produces IL-2 after stimulation by a pigeon cytochrome C peptide (amino acids 81-104) in the context of E^k that was carried as described previously (11,14). Lympholyte-M purified A.E7 T cells were pre-treated for 48 hours with MLA144 gibbon ape leukemia cell supernatant to provide 100 units/ml of IL-2 activity. T cells were harvested, washed 3 times with medium (Click's medium with 10% fetal calf serum, 2 mM glutamine, and 50 μM β-mercaptoethanol added; Biofluids, Inc.) and stimulated in 96-well dishes. Antigen stimulations contained 2 X 10^4 T cells, 1 X 10^4 DCEK (E_α,$B_\beta{}^K$ - expressing L cell transfectants, a gift of Dr. Ronald Germain, NIH) APCs given 3000 Rads, and I μM purified pigeon cytochrome C peptide (amino acids 81-104) in 200 μL total volume. For thymidine uptake, after 24 hours, 0.5 μCi of [^{3}H]TdR (Amersham) was added, incubation was continued for 8 hours, and samples were then assayed by scintillation counting. For photomicroscopy, after 40 hours of stimulation, the medium was replaced with 0.4% trypan blue in phosphate buffered saline (PBS, 0.8 mM potassium phosphate, 154 mM sodium chloride, and 2.9 mM sodium phosphate, pH 7.4) for 10 minutes. The stain was removed and the wells gently washed three times with PBS only. Photomicrographs were made on a Zeiss Axiovert 405 M microscope using Hoffman modulation contrast optics. Antibody stimulations used 96-well plastic culture dishes coated with 10 μg/ml solutions of protein A column-purified anti-CDεMAb (145-2C11) (15) in PBS for 4 hours at 370C. Wells were washed two times with PBS, once with medium, and filled with 5 X 104 A.E7 T cells in 200 μL of medium. Lymph node T cells (for Tables 2 and 3) from axillaryl inguinal, and mesenteric nodes excised from BALB/c mice wer placed int medium containing 3 μg/ml concanavalin A

f r 48 hours, then treated with 10 μg/ml α-methylmannoside f r 30 minutes, washed extensiv ly, and placed in culture f r 48 hours with either 3 or 100 units of Il-2. Antibody stimulations (F23.1 and RR4-7) were in 75 cm^2 culture flasks coated with antibodies as in Fig. 2 and inoculated with 1 x 10^7 cells in 12 mls medium containing either 5 or 10^7 cells in 12 mls medium containing either 5 or 100 units IL-2/ml. Cells were harvested, isolated by Lympholyte-M, and stained for cytometry. DNA preparations of A.E7 cells stimulated with IL-2 and anti-CDϵ (scaled to 5 mls) were carried out as described previously (5).

<u>Figure 2</u>: Vβ8 samples (left panels) were stained with MAb KJ16-133 (20) which detects Vβ8.1,8.2 TCRs and Vβ6 samples (right panels) were stained with MAb RR4-7[18] for Vβ6 TCRs. Histograms are relative fluorescent intensity versus cell number; positive cells, as gated by the dotted line, are percentages of total T cells. Female, six-week-old BALB/c mice were injected with Staphyloccocal entertoxin B (Sigma) diluted in 250 μL sterile 1X PBS in the tail vein as follows: day 0 - 500 μg, day 2 - 125 μg, and day 4 - 125 μg. Lymph node T cells did not express IL-2 receptor α chain until 12 hours after the first SEB injection; therefore, I.P. injections of 800 μg of MAb 3C7 were initiated 12 hours after the first SEB dose, and given every 12 hours until the experiment ended. MAb 3C7 has been shown to block IL-2 responses <u>in vitro</u> (ref. 21, 22 and M.J.L., unpublished results). MAb 11b11 was given similarly in 1 mg doses. Each MAb injection was given in 300 μL of 5% dextrose in water, which provided a simple metabolite and hydration to prevent mortality of the mice during the course of each experiment. After eight days, the mice were sacrificed, and lymph node cells were directly stained. Staining for flow cytometry was carried out in 1X PBS with 0.1% bovine serum albumin and 0.1% sodium azide with pre-determined dilutions of primary antibody (mouse immunoglobulin (Ig) γ2a MAb F23.1 or rat IgG2b, KJ16-133 for Vβ8 or rat IgG2b RR4-7 for Vβ6) followed by either a fluorescein isothiocyanatec njugated g at anti-mouse IgG2a (Southern Biotechn logy) or a goat $F(ab')_2$ anti-rat IgG

H and L (Caltag Laboratories). CD4 was detect d with phycoerythrin-conjugated anti-L3T4 antibody (Becton - Dickinson). Minor residual dead cells were gated by propidium iodide. Samples were 50,000 events analyzed with 3 decade logarithmic amplification on a Becton Dickinson FACS 440 dual laser cytometer interfaced to a Digital Equipment Corporation PDP 11/24 computer and plotted as isocontours of total cell number.

Figure 3: Human peripheral blood mononuclear cells were purified by Ficoll density gradient centrifugation from blood packs obtained from anonymous donors through the Department of Transfusion Medicine at the National Institutes of Health. The cells were incubated in RPMI 1640 medium with 10% fetal calf serum, and aliquots of cells were given 5 μg/ml concanavalin A for 2-3 days. Cells were then harvested, quantitated, and incubated in flat-bottom plastic dishes precoated with either 0, 1, 5 or 50 μg/ml OKT3 MAb. After 2-3 days, 4-6 cell counts were performed and averaged for each point.

The findings described above establish a direct role for IL-2 in clonal elimination of mature T cells, which is postulated to be a mechanism of extra-thymic tolerance (1,4,8,9). Recently, Kawabe and Ochi have shown that the loss of mature Vβ8 cells following SEB injection is the result of apoptosis (1). This study demonstrates that loss of $V\beta8^+$ T cells may be faster and greater in magnitude if larger amounts of SEB are repeatedly administered. This would support the model that antigen re-stimulation of T cells under the influence of IL-2 will cause apoptosis.

How does IL-2, which is well known for its mitogenic effect on T lymphocytes, paradoxically program the same cell-type for apoptosis? One possibility is that IL-2 serves only to drive T cells into the division cycle, which has been recently suggested to pre-dispose thymocytes and γδ T cells to death (27,28). If this is true, then any successful immune response could pre-dispose mature αβ T cells to apoptosis. Alternatively, IL-2 could pr vide a qualitatively or quantitatively distinct signal that entrains ap ptosis to

antigen receptor stimulation. in either case, in evaluating IL-2 as a therapeutic agent in humans, it will be important to consider its unexpected ability to pre-dispose T cells to apoptosis.

EXAMPLE 2

This example shows that T cell death can be caused by stimulation with high doses of antigen without exogenously administered IL-2. In particular, the data presented here show that the T cell death depends on IL-2 produced by the T cells.

Figure 6 shows results of experiments in which the non-transformed, CD4+ T_H1 T lymphocyte clone A-E7 was stimulated with increasing concentrations of its cognate peptide -- pigeon cytochrome c amino acids 81-104. $1x10^4$ A-E7 lymphocytes were stimulated with peptide antigen using $5x10^5$ irradiated syngeneic splenocytes as antigen presenting cells in flat bottom 96 well plate. Samples were incubated for 72 hours then pulsed with 1 μCurie of ^{3}H-thymidine for 18-20 hours.

Figure 6 shows that proliferation, as measured by incorporation of [^{3}H]-thymidine (line with squares), peaks at 0.01 μM and then decreases at higher doses. At the greatest antigen dose of 10 μM proliferation is 10% of the maximum. Despite the apparent proliferative blockade, production of interleukin-2 (IL-2) is maximal in the suppressive range (line with circles).

These results demonstrate that supraoptimal concentrations of antigen cause suppression of ^{3}H-thymidine incorporation in the presence of maximal IL-2 production.

The results presented in Figure 7 show that T lymphocytes die at high antigen doses. A-E7 lymphocytes ($5x10^4$ per well) were incubated with no (left panel), 0.1 μM (middle panel) or 10 μM (right panel) pigeon cytochrome c peptide in the presence of 50 fold excess of irradiated DCEK antigen-presenting cells. Following a 48 hour incubation the cultures were stained with trypan blue for 10 minutes, rinsed, then photographed using Hoffman modified optics in a Z iss Axiovert 405 M microscope.

Cells appearing dark are unable to exclude the dye and thus are non-viable. As can be seen, the 10 μM sample had a significant number of dead cells whereas at low or 0 antigen doses very few cells are dead. These results demonstrate that high antigen doses cause significant T cell death.

The results in Figure 8 show that decreased T cell number quantitatively accounts for the suppression of ^{3}HTdR cpm.

In order to quantitate the amount of death occurring at high antigen dose a FACS viability assay was devised. T lymphocytes (1×10^4 A-E7) were incubated at the indicated concentration of their cognate antigen with 50 fold excess of syngeneic splenocytes for 72 hours. The samples were harvested, rinsed, then stained with a fluorescein labelled anti Vα11 antibody and anti-CD4 antibody in order to determine the fate of the A-E7 cells following stimulation. In addition, samples were stained with propidium iodide as a means of excluding non-viable (propidium iodide positive) cells. Panel a. is a representative experiment in which CD4+ cells are analyzed for the presence of Vα11 T cell receptor. The experiment shows an antigen specific increase in cell number at 0.01 μM. At higher doses, however, cell number is dramatically reduced. The 10 μM sample has 80% fewer viable cells than the 0.01 μM point. Moreover, at 10 μM there are 20% fewer cells than the 0 antigen point, demonstrating a deletion below the baseline number of cells added to the experiment.

In order to determine if antigen specific cell death would occur in primary T lymphocytes, the same experiments were conducted in lymph node cells harvested from mice carrying the transgenic construct for the myelin basic protein T cell receptor (Vα2.3;Vβ8.2) which recognizes the myelin basic protein peptide Ac1-11. Cells were stimulated with the indicated concentrations of Ac1-11 for 5 days then stained for analysis with anti Vα2.3 antibodies and anti-CD4 antibodies. Panel b. is a representative experiment showing the antigen specific loss of viable T lymphocytes at high antigen concentrations. In this case, the 100 μM sample has 95% fewer

cells than the 1.0 μM point. These exp riments dem nstrate that antigen specific death of b th T cell clones and primary lymphocytes can account for the observed high d se suppression of proliferation.

The results in Figure 9 reveal that endogenous production of IL-2 is necessary and sufficient for antigen specific T cell death. Using the FACS viability assay described above, cell number for A-E7 lymphocytes was quantitated at increasing concentrations of antigen either with or without inclusion of 3C7, an antibody which binds the alpha chain of the IL-2 receptor and blocks IL-2 bioactivity. At 10 μM peptide antigen there were 75% fewer live cells as compared to the maximal concentration. In the presence 3C7 this reduction in cell number was abrogated. These results demonstrate that specifically reactive T cells can be deleted at high antigen doses without the requirement of exogenous IL-2, and that this deletion is blocked when IL-2/IL-2R interaction is disrupted.

The data presented in figures 6-9 demonstrate that high dose suppression can be caused by propriocidal death, a mechanism which is initiated under conditions of strong TCR stimulation (such as high concentrations of antigen) and IL-2 from either endogenous production of from exogenous sources.

EXAMPLE 3

This example provides evidence that repetitive administration of antigen to animals causes deletion of specifically reactive T lymphocytes *in vivo* without affecting non-reactive "bystander" cells and that deletion of the pathogenic clones ameliorates disease.

In particular, this example provides evidence demonstrating the efficacy of the present invention in animal models for multiple scelorosis, autoimmune uveitis disorders, and allergic response

Experimental Allergic Encephalomyelitis

Experimental allergic encephalomyelitis (EAE) is considered by th se skilled in the art f neuroimmunologic

diseases to be an animal model of neuroimmunologic diseases such as multiple sclerosis and acute disseminated encephalomyelitis. Agents that suppress animal EAE lesions are considered to be of potential clinical utility in the treatment of neuroimmunologic diseases. For example, a number of cytotoxic agents have been shown to suppress EAE lesions in animals. Some of these agents have shown clinical efficacy in patients with multiple sclerosis.

Figure 10 describes the protocol for induction and treatment of EAE. Donor mice were immunized with 400 μg myelin basic protein (MBP) in complete Freund's adjuvant Ten days later, draining lymph nodes were harvested, then made into a cell suspension and stimulated with myelin basic protein in vitro to further increase the frequency of MBP responsive cells. The cells are rinsed then injected into recipient mice. Symptoms of disease ensued 6-9 days later often beginning as tail paralysis that progressed quickly to hind limb then complete body paralysis. The disease follows a remitting and relapsing course.

The clinical grading of the disease in the following experiments was as follows: 0 - normal; 1 - limp tail; 2 - moderate hindleg paresis; 3 - sever hindleg paresis; 4; hindleg paralysis; 5 - whole body paralysis; 6 - death.

Figure 11 shows the results from experiments using repetitive injections of MBP and IL-2 to prevent EAE. 400 μg MBP was administered intravenously twice daily on days 0, 2 and 4 post transfer. 30,000 units of IL-2 was administered twice a day on days 0-4. The mice (5 mice/group) were followed for 65 days. The data demonstrate that the MBP/IL-2 therapy dramatically reduces the severity of the disease as seen by the reduction in mean clinical score. In addition, the incidence of disease was lowered since 100% of untreated mice got sick whereas only 40% of treated mice developed the disease.

Figure 12 shows that repetitive injections of 400μg MBP can prevent progression of early stage disease. In this experiment MBP administration was initiated on day 9 post transfer when the first mouse developed symptoms of dis as .

At this point all the mice in the group were treated with MBP then again on days 11, and 13. The data show a significant difference on severity of disease. Also, only 20% of treated mice developed disease whereas 100% of untreated animals got sick. The experiment demonstrates that the antigen therapy can abrogate progression of early stages of disease.

Figure 13 shows that repetitive injections of 400μg MBP blocks relapses of disease, thus demonstrating the effectiveness of this therapy to ameliorate existing disease. Following the first remission the mice were split into 2 groups: treatment and no treatment. The treatment group received 2 i.v. injections of MBP on days 17, 19, and 21 post transfer. The graph shows that the untreated animals, following their remission progressed to have sustained relapses. The treated mice experienced no such relapse, demonstrating that the therapy abrogates progression of chronic disease.

Figures 14 and 15 present the results of experiments which correlate amelioration of disease with activation of the propriocidal mechanism by showing antigen specific deletion of pathogenic T lymphocytes in vivo.

The first experiments involved repetitive doses of MBP antigen delete in vivo mature T lymphocytes stained with the vital dye DiI. As discussed above, following priming of donor mice, lymphocytes are further activated in vitro with MBP. Prior to transfer the cells were stained with the vital dye DiI, which is stably incorporated into the plasma membrane. The dye, when excited at the proper frequency has a characteristic emission pattern that can be detected by FACS thereby allowing detection of cells stained with the dye. The dye is known to be stable for greater than 4 weeks which allows ample time to transfer stained cells, treat mice, then harvest lymph nodes and spleen to analyze for the presence of encephalitogenic lymphocytes which would be DiI positive.

Figure 14 shows that animals which received stained cells without therapy get disease as predicted (grade 3), whereas animals treated with MBP did not get sick. As a control for antigen specificity, 400μg ovalbumin was

administered t another group of mice. Ovalbumin treatm nt provided no protection fr m disease. To determine if antigen specific deletion occurred we analyzed by FACS the spleens of each mouse collecting all CD4+ lymphocytes then analyzing for the presence of DiI. As indicated in Figure 14 non-treated animals had the highest frequency of CD4+/DiI+ cells. In contrast MBP treated mice had levels of DiI signal comparable to untreated mice suggesting that the reduction the in number if DiI+ cells was MBP specific.

Figure 15 presents the results of experiments showing that repetitive doses of MBP antigen delete MBP transgenic lymphocytes in vivo. In these experiments, TCR transgenic lymphocytes were activated in vitro by their cognate peptide Ac1-11 and transferred into syngeneic mice. As show in Figure 8, these lymphocytes undergo death at high concentrations of antigen. The transgenic TCR were detected using antibodies specific for the receptor.

The mice received 3×10^7 activated lymphocytes and then treatment with 400μg of either MBP or ovalbumin twice a day i.v. on days 0, 2, and 4 post transfer. A third group received no treatment. Figure 15 demonstrates, first al all, that the transgenic cells can induce disease; untreated mice developed grade 4 disease.

In order to correlate level of disease with frequency of reactive cells lymphocyte preparations from mesenteric lymph nodes were made. Three color staining was preformed with antibodies against CD4, Vα2.3 and Vβ8.2. For FACS analysis only CD4+ cells were collected. The FACS plots in Figure 15 show CD4+/Vβ8.2+ cells then plotted for the frequency of Vα2.3 positive cells. The highest frequency of cells was seen in the untreated animals, which correlates well with the level of disease which was the highest of the tested groups. In contrast, mice treated with MBP had 62% fewer Vα2.3 than the untreated groups demonstrating a significant deletion of reactive T cells. Mice treated with ovalbumin had no such deletion nor were they protected from disease demonstrating that the effect is antigen specific.

Experimental Allergic Uveitis

The present invention can be used for targeted T lymphocyte deletion with other antigens, as shown using a different autoimmune model-- experimental allergic uveitis (EAU) a mouse model for human autoimmune uveitis disorder.

The protein which causes EAU has been isolated, it is interphotorecptor retinol-binding protein (IRBP) a protein found in the retina. EAU is initiated by inoculation of genetically susceptible mice with an emulsion of 50 μg IRBP and complete Freund's adjuvant (CFA). 12-18 days post inoculation ocular inflammatory infiltrates ensue. After 3-4 weeks scarring with resultant permanent damage occurs. Definitive scoring of disease requires histopathology.

To demonstrate the clinical efficacy of propriocidal regulation in therapy for EAU a protocol as described in Figure 16 was devised. Mice were initially primed with an IRBP/CFA emulsion on day 0, then split into different treatment groups. Groups received a total of 4 repetitive injections of IRBP in incomplete Freund's (IFA) either qD (each day) for first 4 days, or q3D (every third day). Additionally, certain groups received concomitant injections of 30,000 units IL-2 or IL-2 alone that began day 3 post inoculation and ran through day 12.

Figure 17 shows scoring of EAU by ocular histopathology. Scoring was performed as described in Caspi et al., J. Immunol. 136:9928-9933 (1986). Mice 1-4 which received only vehicle with no IRBP, showed no signs of disease. IRBP alone without further injections (mice 5-7) had the most significant disease ranging in severity from grade 1-3. In the treatment groups, IL-2 seemed to have no protective effect when administered without IRBP. In all groups receiving repetitive injections of IRBP, mice were somewhat protected from disease as compared to the untreated controls. Interestingly, the timing of the repeat doses had a significant effect since groups treated q3D have less severe disease than untreated controls as well as the qD treatment group. Addition of exogenous IL-2 to this regimen resulted in the m st dramatic protection. Mice 23-25 which received IRBP

q3D and IL-2 are disease free, indistinguishable from unmanipulated normal animals.

Allergic Responses associated with IgE

Figure 18 shows the schedule of immunization and treatment in the production of serum IgE in response to chicken egg albumin. To immunize for the production of serum IgE, 10 μg of chicken egg albumin was given in alum adjuvant IP in BABB/C mice. To treat the IgE response to this immunization, 0.5 mg of chicken egg albumin in phosphate-buffered saline was given IP on days 1, 3, and 5. In a separate treatment trial, animals were given the same immunization and treatment with chicken egg albumin, but were also given 2 doses of $1x10^4$ units of human recombinant IL-2 each day from days 1 through 5.

Figure 19 shows the measurement of serum IgE. The measurement of serum IgE in each group of four mice revealed significant production of IgE in the animals that received the immunization with chicken egg albumin but no treatment (Group 1, n=4). Treatment with either antigen alone (Group 2, n=4) or with antigen + IL-2 (Group 3, n=4) both led to dramatic reductions in the level of IgE with a slightly better response for the latter group. Note that unimmunized animals had essentially no detectable IgE (<0.2 μg/ml). These results demonstrate that treatment with antigen and IL-2 reduces the serum levels of allergic immunoglobulin IgE that plays a role in food allergy to eggs.

Example 4

This example shows that human T cells derived from a patient diagnosed with multiple sclerosis that are specifically reactive with myelin basic protein can be deleted using the present invention. T cells were first stimulated for 48 hours, washed, and incubated with 300 units/ml IL-2 for 48 hours. The cells were then incubated on plastic dishes coated with 5/μg/ml of an antibody against the human T cell receptor (TCR)/CD3 complex (MAb 64.1, which had been shown to potently activate T cells) for an additional 48 hours in the continued presence of 300 units/ml of IL-2. Fl w cytom try analysis presented in Figure 20 shows that th samples f

cells carried in IL-2 and not rechallenged through the TCR/CD3 c mplex (n ne) contained 25790 cells/unit v lume whereas cells that had been restimulated hád 2974 cells/unit v lume. Thus, restimulation of human T cells exposed to high IL-2 caused a greater than 88% deletion of these cells.

The invention being thus described, it will be obvious that the same may be varied in many ways. Such variations are not to be regarded as a departure from the spirit and scope of the invention, and all such modifications as would be obvious to one skilled in the art are intended to be included within the scope of the following claims.

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WHAT IS CLAIMED IS:

1. A method for treating or preventing a disease in a human or animal caused by antigen-activated T cells, comprising inducing the death by apoptosis of a subpopulation of T lymphocytes that is capable of causing said disease to an extent greater than that of other T lymphocytes.

2. The method of claim 1, wherein said apoptosis is achieved by a cycle comprising challenging via immunization said T cells with a substance selected from the group consisting of an antigen, a peptide, a protein, a polysaccharide, an organic molecule, and a nucleic acid, followed by increasing the amount of IL-2 in said human or animal when said T cells are expressing high levels of IL-2 receptor, so as to cause said T cells to undergo apoptosis upon re-immunization with said substance.

3. The method of claim 2, wherein said antigen, peptide, or protein is selected from the group consisting of one leading to an autoimmune disease, an allergic or atopic disorder, and graft rejection.

4. The method of claim 3, wherein said autoimmune disease is selected from the group consisting of multiple sclerosis, uveitis, arthritis, Type I insulin-dependent diabetes, Hashimoto's thyroiditis, Grave's thyroiditis, and autoimmune myocarditis.

5. The method of claim 3, wherein said allergic disorder is selected from the group consisting of hay fever, extrinsic asthma, insect bite and sting allergies, and food or drug allergies.

6. The method of claim 2, wherein said challenging via immunization is conducted by administering said antigenic peptide or protein at a dose effective to cause said T cells t expr ss high affinity IL-2 receptors and/or to produce and secrete IL-2.

7. The method f claim 2, wherein said challenging via immunization is c nducted by administering said antigenic peptide or protein at a dose between ab ut 10 to about 1000 μg.

8. The method of claim 2, wherein said challenging via immunization is conducted by administering said antigenic peptide or protein orally or intramuscularly.

9. The method of claim 3, wherein said antigenic peptide or protein is selected from the group consisting of myelin basic protein residue 84-102, myelin basic protein residue 143-168, human S antigen, type II collagen, thyroglobulin, Amb a V, Amb t V, an antigen inciting hay fever, an antigen derived from insect venom, an antigen derived from insect saliva, a food antigen, a drug antigen, and a donor class I major histocom-patibility complex antigen.

10. The method of claim 9, wherein said antigen derived from insect venom is antigen V of hornet venom.

11. The method of claim 9, wherein said food antigen is codfish allergen M.

12. The method of claim 2, wherein said challenging via immunization is followed by a period of time between about 12 to about 72 hours before administering an additional high dose of IL-2.

13. The method of claim 2, wherein a high dose of IL-2 is administered intravenously, either as a continuous infusion or as frequent bolus doses.

14. The method of claim 2, wherein a high dose of IL-2 is in the range between about 300 to about 3,000 units/kg/hour continuous infusion, or from about 10^4 to about 10^6 units/kg intravenous b lus.

15. The method of claim 13, wherein said continuous infusi n is conducted for a period of time between about 48 to about 72 hours.

16. The method of claim 2, wherein said cycle is repeated up to an endpoint selected from the group consisting of elimination of in vitro reactivity to said antigenic peptide or protein, amelioration of clinical symptoms, decreased allergic skin test, reduction in serum IgE, and toxicity.

17. The method of claim 9, wherein said donor class I major histocompatibility complex antigen is administered in the form of whole blood, packed cell equivalent, or a washed packed cell transfusion.

18. The method of claim 17, wherein said whole blood is administered in a dose of about 50 to about 200 ml.

19. The method of claim 18, wherein the total amount of whole blood administered is determined by the fluid tolerance of end-stage renal disease in the recipient.

20. The method of claim 19, wherein said cycle is repeated up to an endpoint selected from the group consisting of a diminished requirement for general immunosuppressive medications, graft survival, and adequate function of said graft.

21. The method of claim 2, wherein said cycle comprises challenging via immunization said T cells by repeated administration of said substance without the subsequent exogenous administration of IL-2.

22. The method of claim 21, wherein said cycle of repeated administration is performed at a short time interval.

23. The method of claim 22, wherein said time interval is in the range of from about one to about five days.

24. The method of claim 22, wherein said time interval is in the range of from about one to about three days.

No Antigen

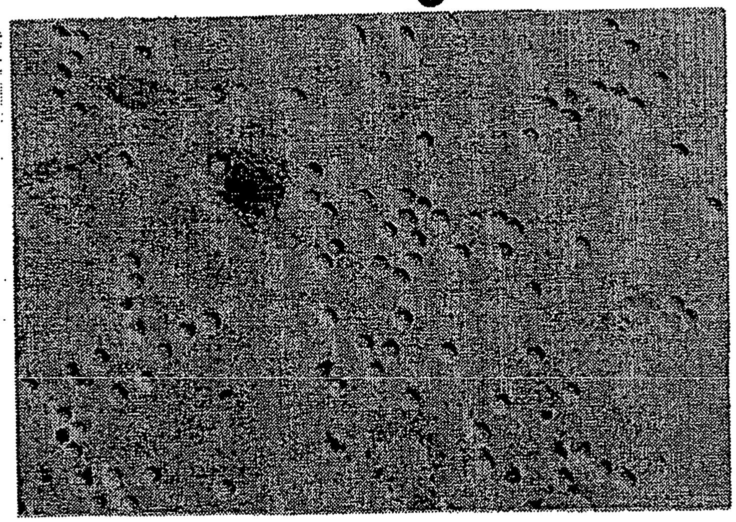


FIG. 1A1

Untreated

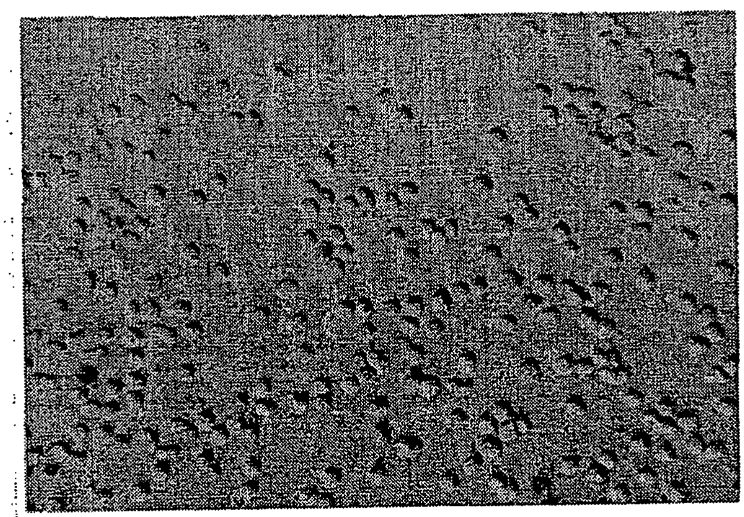


FIG. 1A2

1μM Antigen

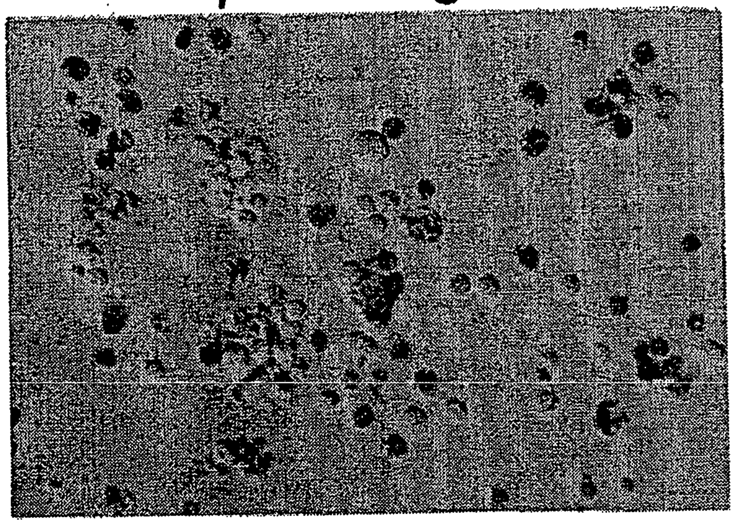


FIG. 1A$_3$

Anti-CD3ε

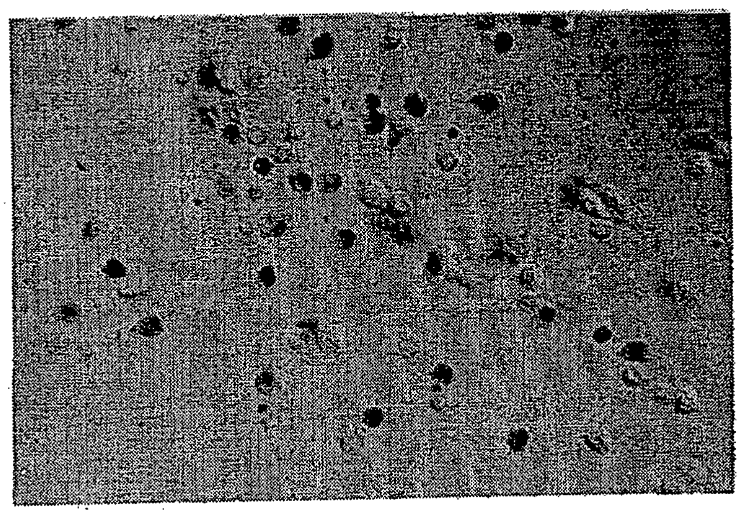


FIG. 1A$_4$

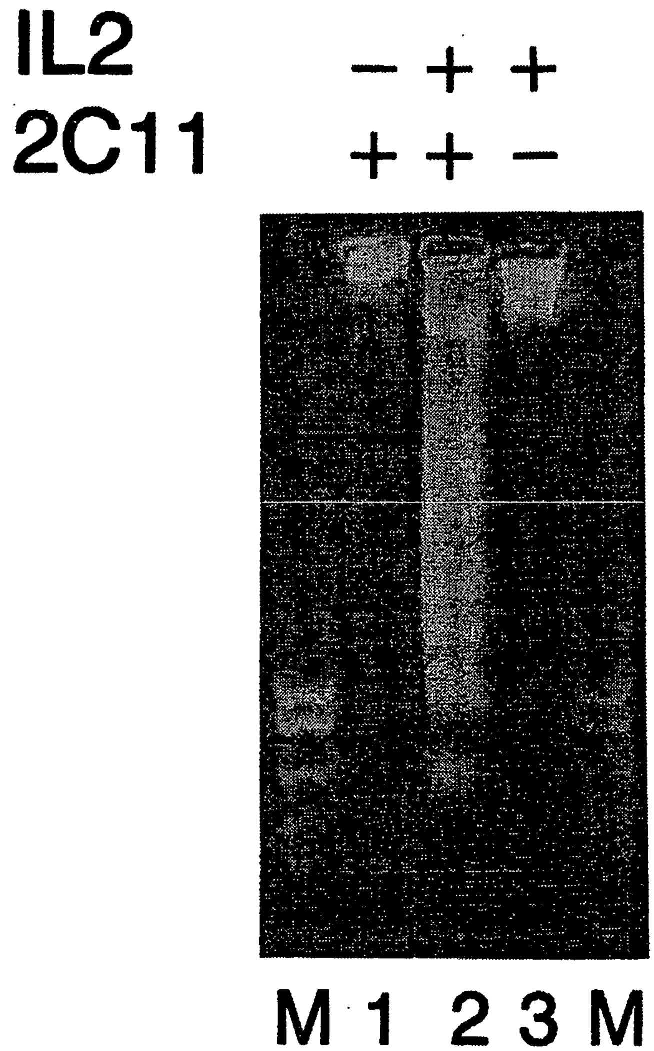


FIG. 1B.

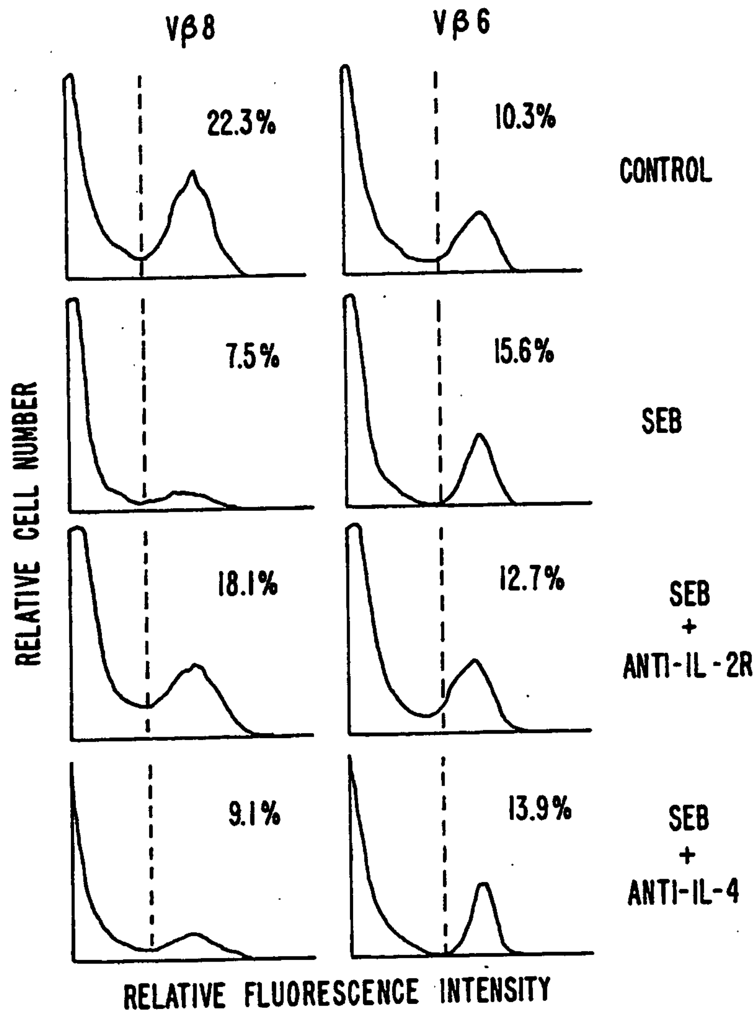
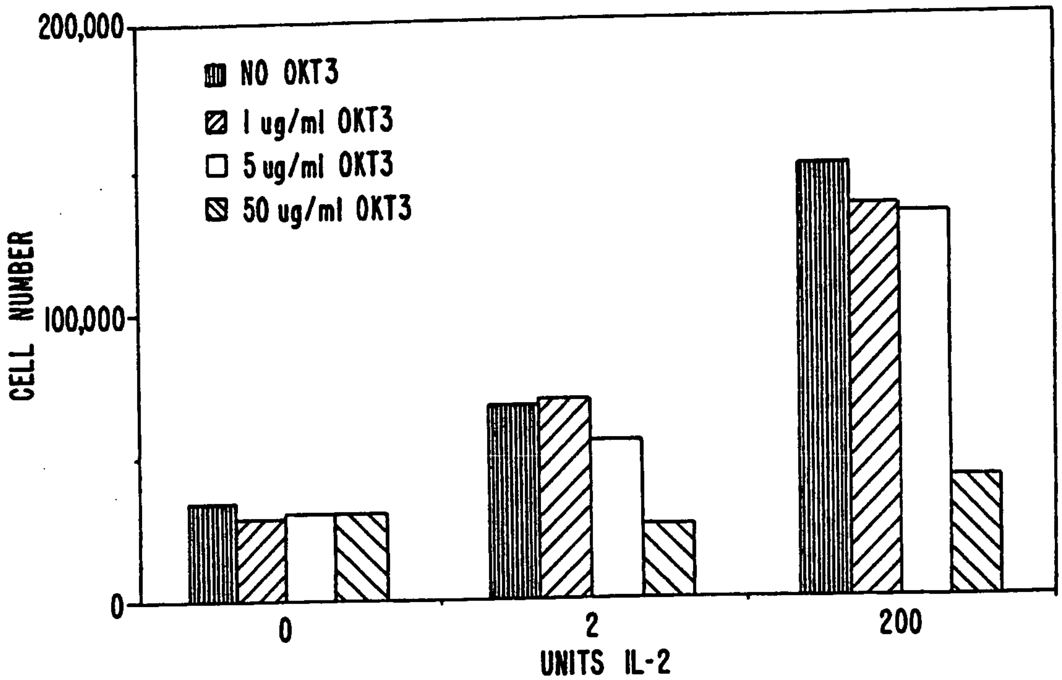
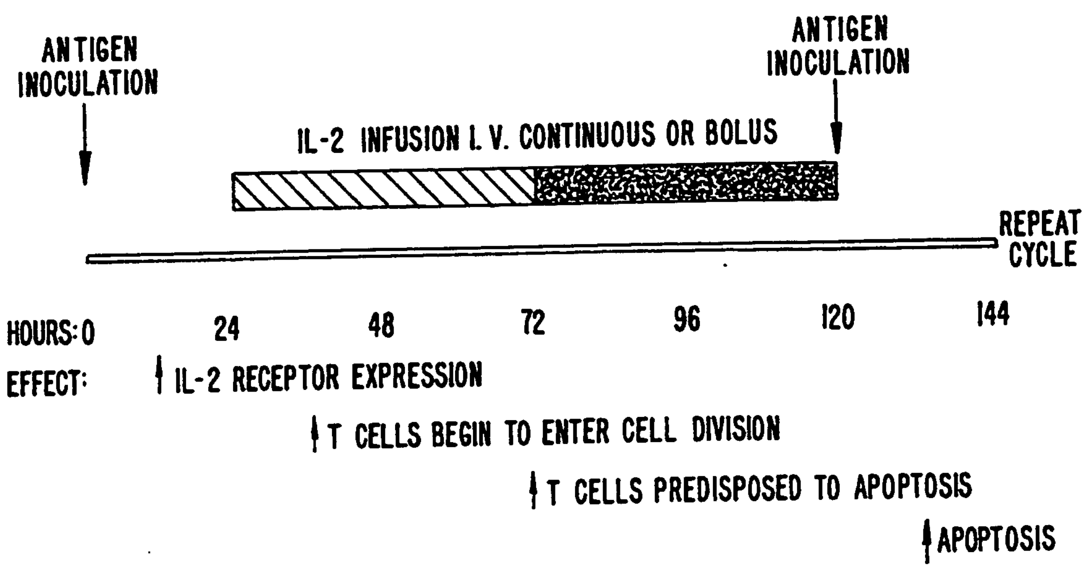

Vβ8
Vβ6
22.3%
10.3%
CONTROL
7.5%
15.6%
SEB
18.1%
12.7%
SEB
+
ANTI-IL-2R
9.1%
13.9%
SEB
+
ANTI-IL-4
RELATIVE CELL NUMBER
RELATIVE FLUORESCENCE INTENSITY

FIG. 2.



200,000
100,000
0
CELL NUMBER
NO OKT3
1 ug/ml OKT3
5 ug/ml OKT3
50 ug/ml OKT3
0
2
200
UNITS IL-2

FIG. 3.



ANTIGEN INOCULATION
ANTIGEN INOCULATION
IL-2 INFUSION I.V. CONTINUOUS OR BOLUS
REPEAT CYCLE
HOURS: 0
24
48
72
96
120
144
EFFECT:
IL-2 RECEPTOR EXPRESSION
T CELLS BEGIN TO ENTER CELL DIVISION
T CELLS PREDISPOSED TO APOPTOSIS
APOPTOSIS

FIG. 4.

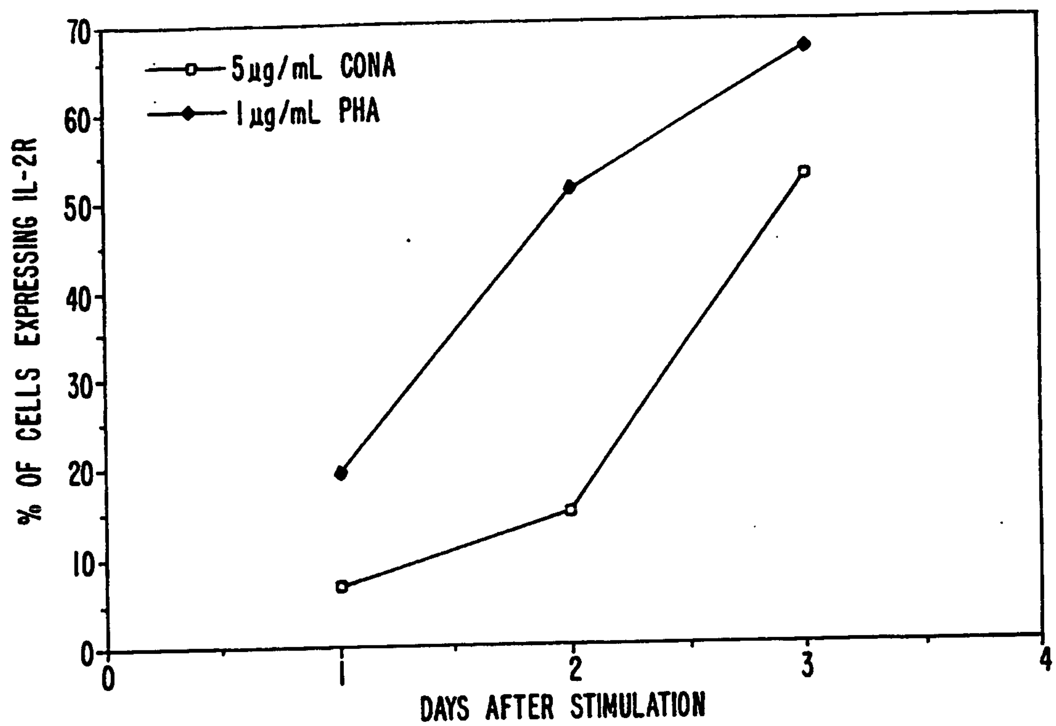

5µg/mL CONA
1µg/mL PHA
% OF CELLS EXPRESSING IL-2R
70
60
50
40
30
20
10
0
0
1
2
3
4
DAYS AFTER STIMULATION

FIG. 5.

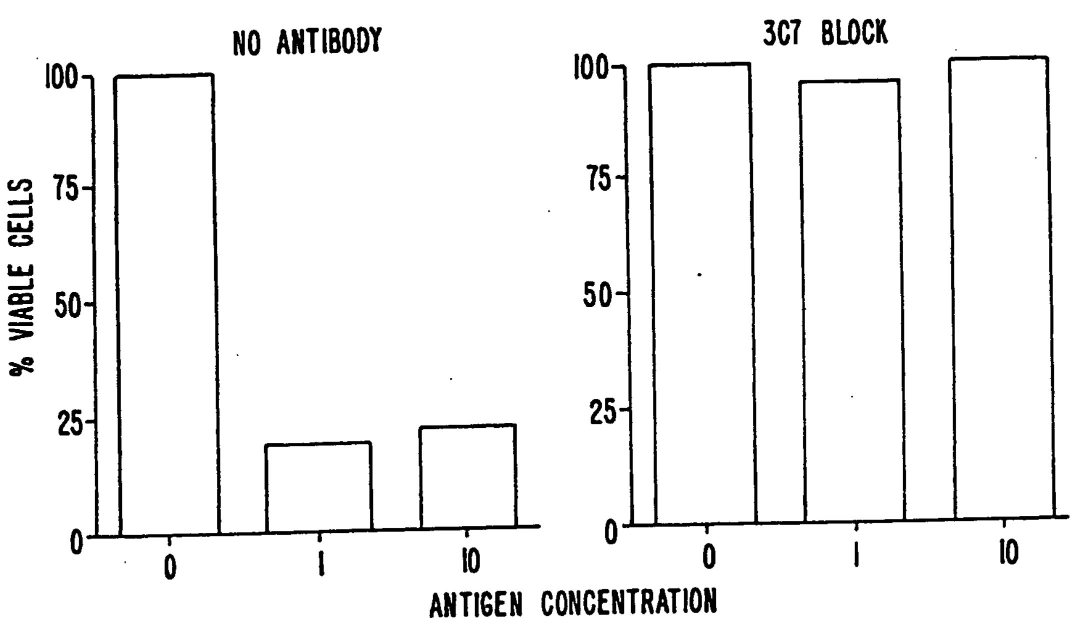

NO ANTIBODY
3C7 BLOCK
% VIABLE CELLS
100
75
50
25
0
0
1
10
ANTIGEN CONCENTRATION

FIG. 9.

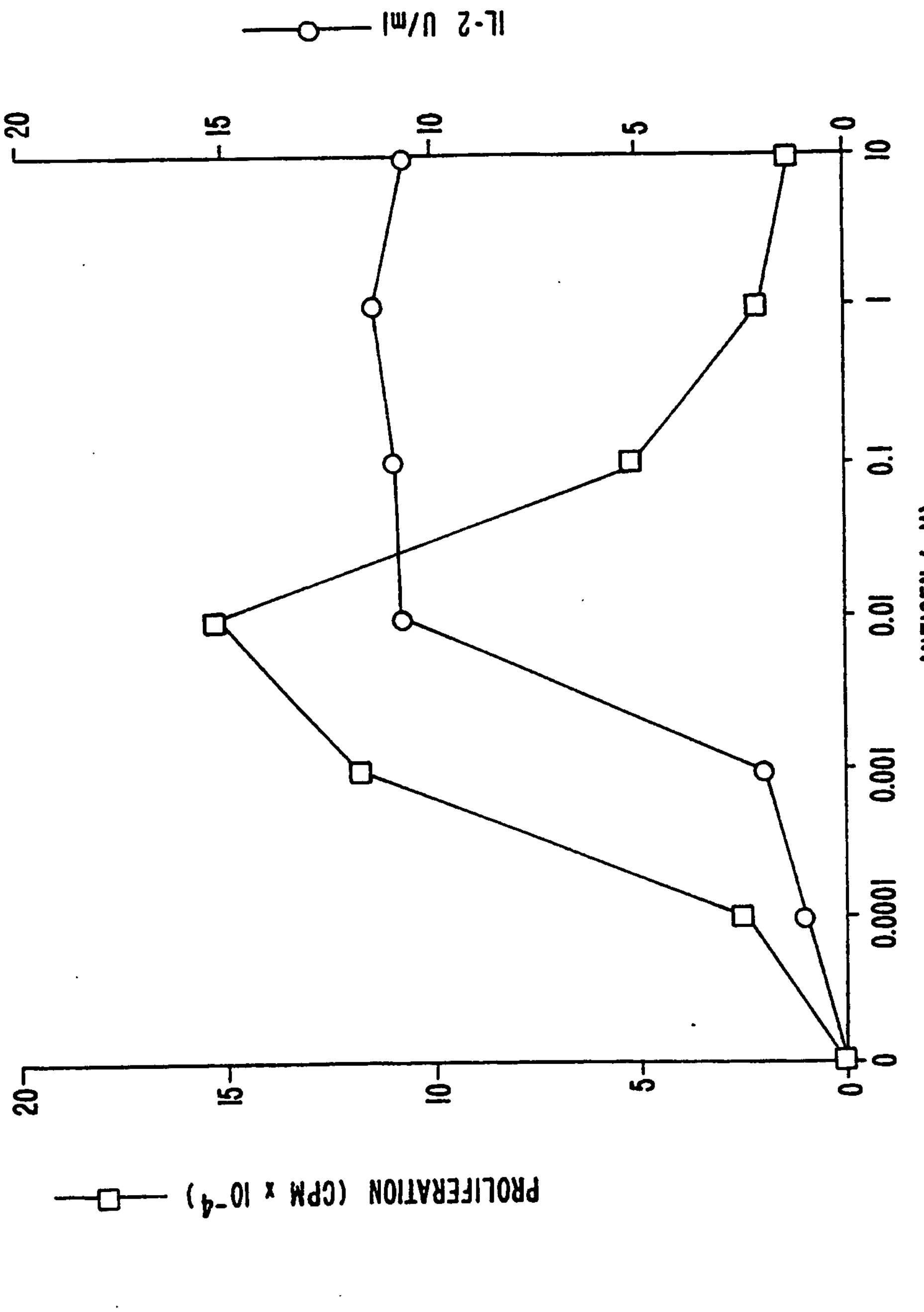
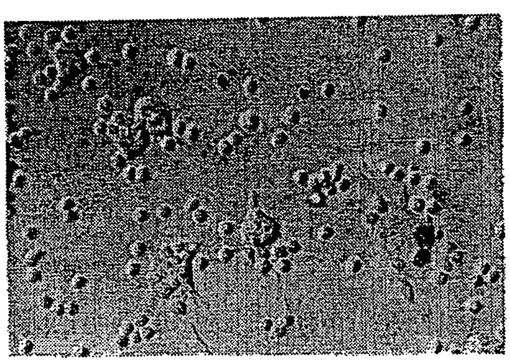
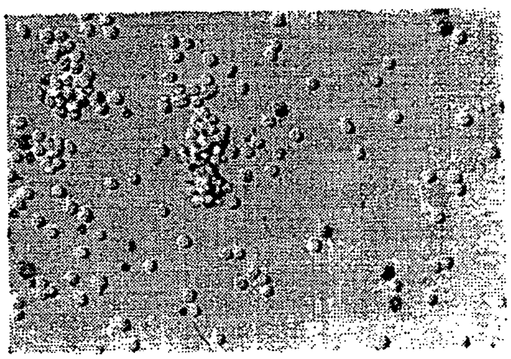

IL-2 U/ml
PROLIFERATION (CPM x 10^{-4})
ANTIGEN (μM)
0
0.0001
0.001
0.01
0.1
1
10
0
5
10
15
20
0
5
10
15
20

FIG. 6.



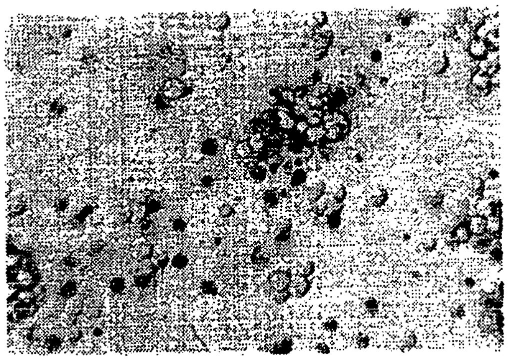
no antigen

FIG. 7A.



0.1 μM antigen

FIG. 7B.



10 μM antigen

FIG. 7C.

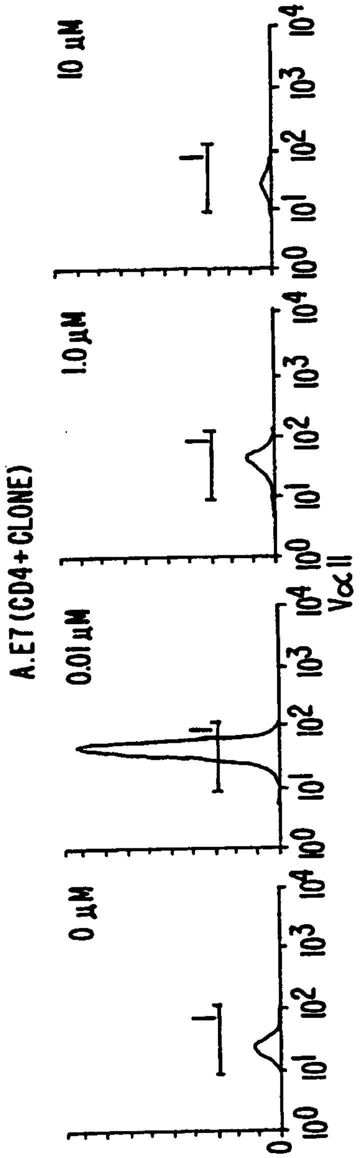

A.E7 (CD4+CLONE)
0 μM
0.01 μM
1.0 μM
10 μM
CELL NUMBER
0
10^0 10^1 10^2 10^3 10^4
Vα11

FIG. 8A.

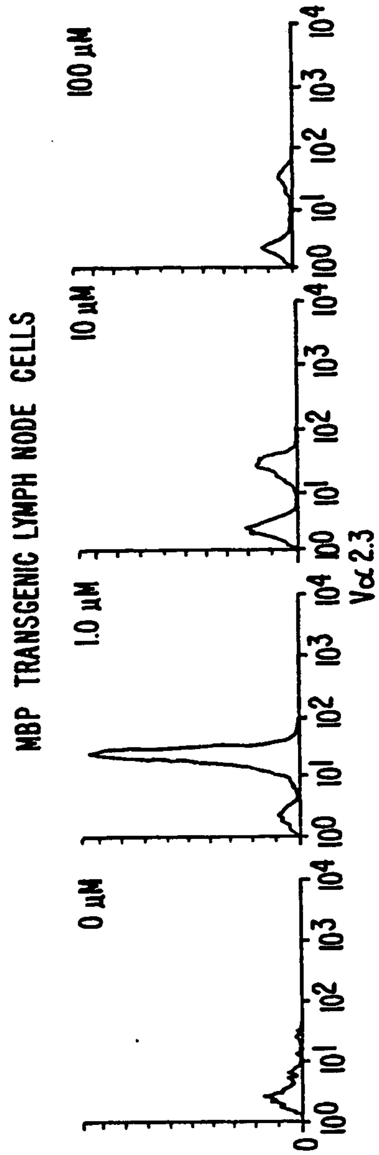

MBP TRANSGENIC LYMPH NODE CELLS
0 μM
1.0 μM
10 μM
100 μM
CELL NUMBER
0
10^0 10^1 10^2 10^3 10^4
Vα2.3

FIG. 8B.

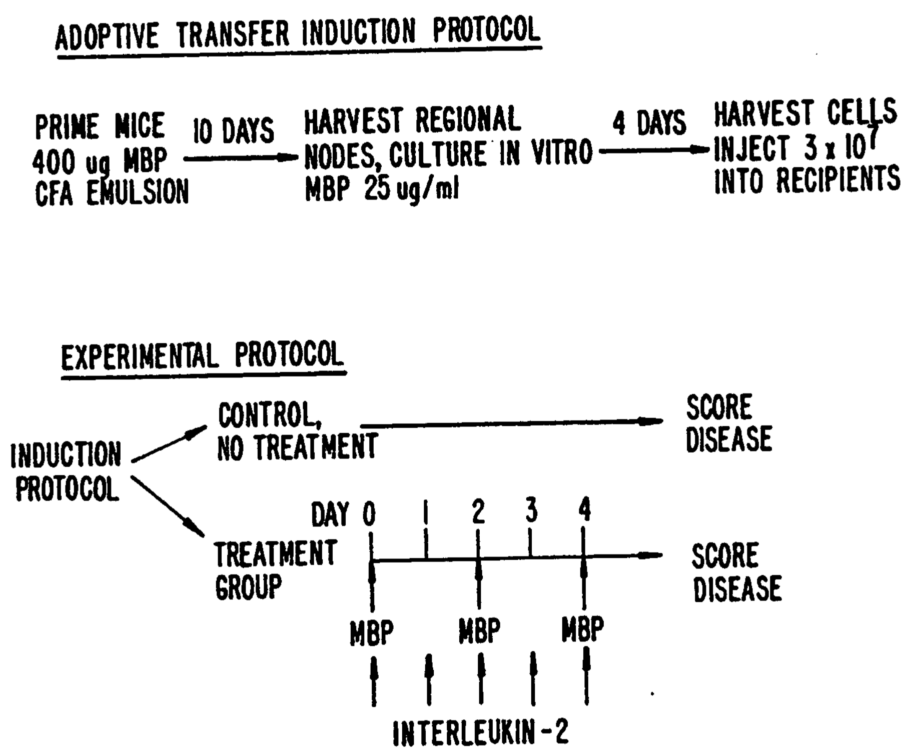

ADOPTIVE TRANSFER INDUCTION PROTOCOL
PRIME MICE 400 ug MBP CFA EMULSION
10 DAYS
HARVEST REGIONAL NODES, CULTURE IN VITRO MBP 25 ug/ml
4 DAYS
HARVEST CELLS INJECT 3 x 10⁷ INTO RECIPIENTS
EXPERIMENTAL PROTOCOL
INDUCTION PROTOCOL
CONTROL, NO TREATMENT
SCORE DISEASE
DAY 0 1 2 3 4
TREATMENT GROUP
SCORE DISEASE
MBP
MBP
MBP
INTERLEUKIN-2

FIG. 10.

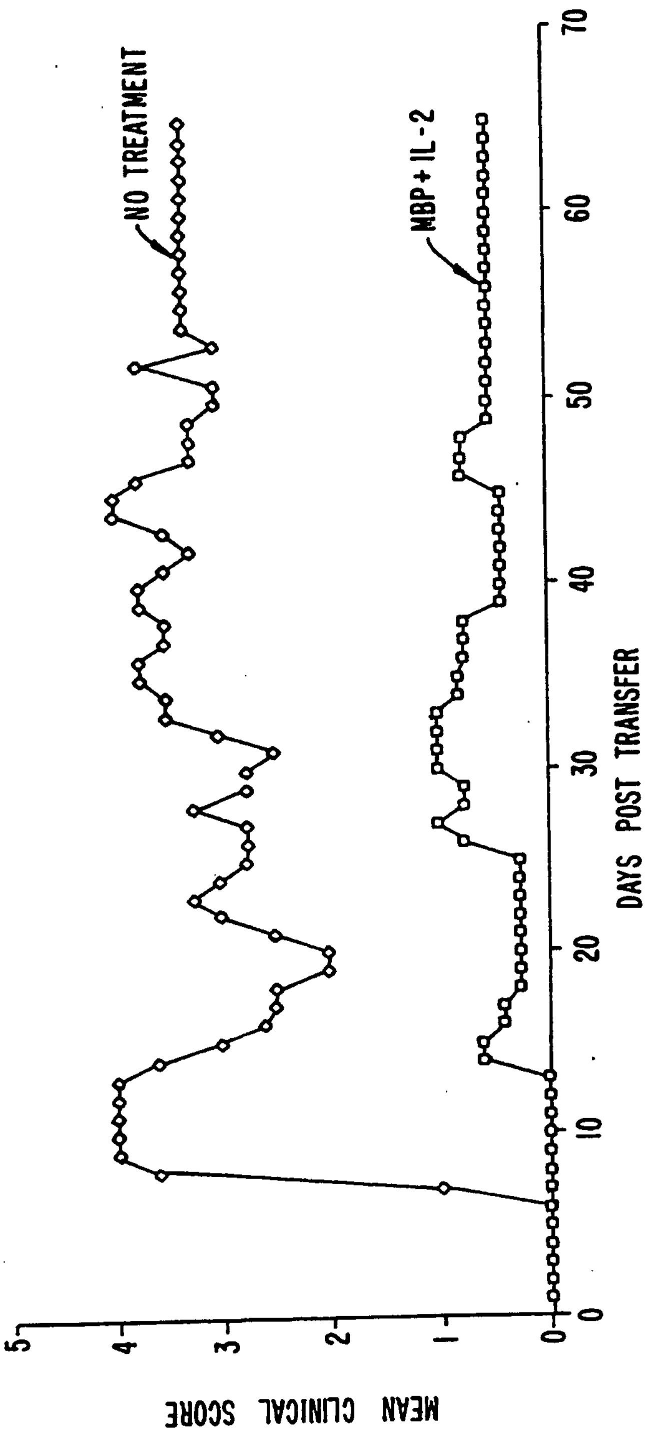

NO TREATMENT
MBP + IL-2
MEAN CLINICAL SCORE
DAYS POST TRANSFER
0
1
2
3
4
5
10
20
30
40
50
60
70

FIG. 11.

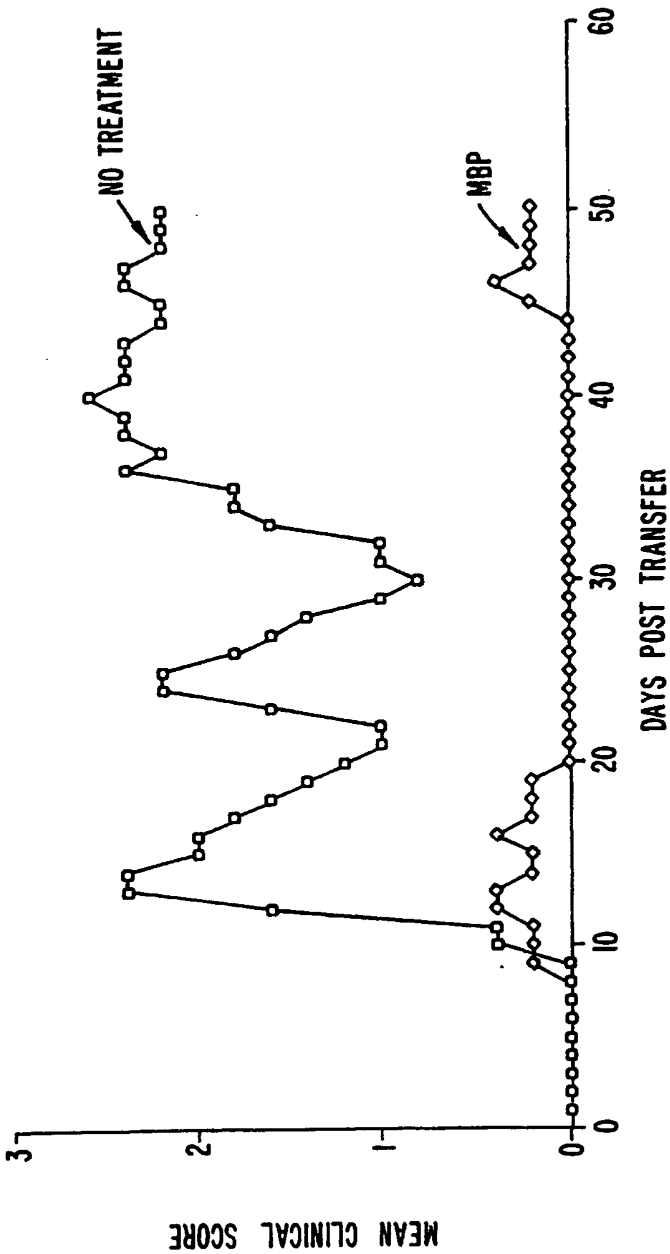

NO TREATMENT
MBP
MEAN CLINICAL SCORE
0
1
2
3
DAYS POST TRANSFER
0
10
20
30
40
50
60

FIG. 12.

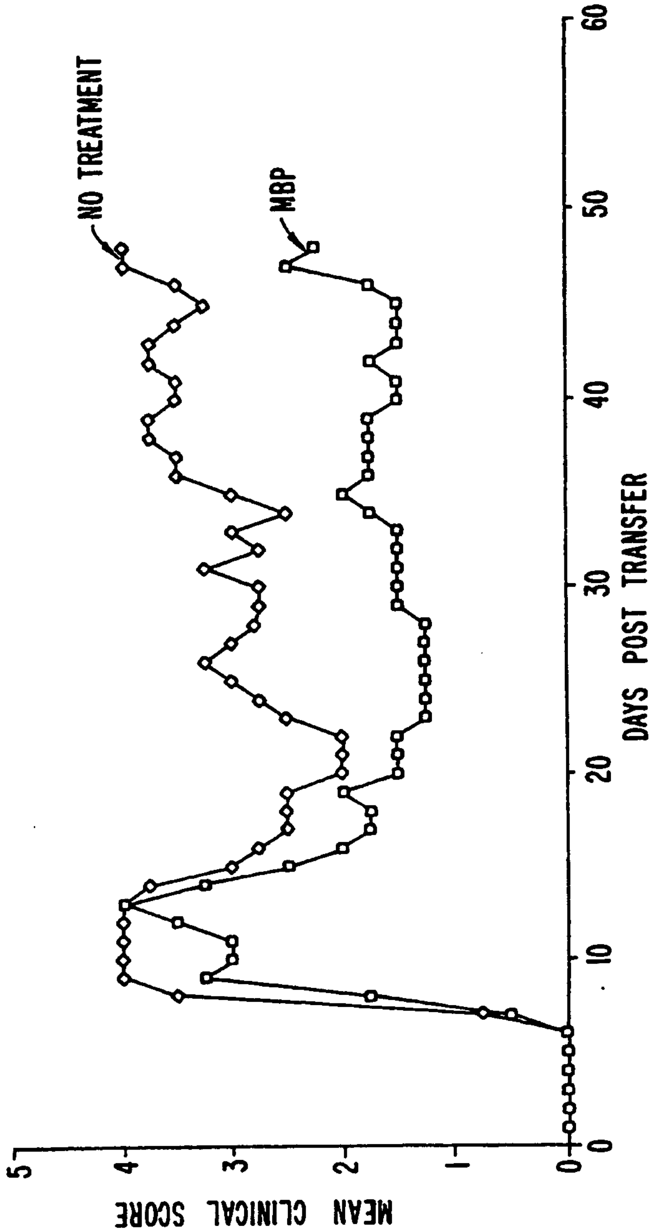

NO TREATMENT
MBP
MEAN CLINICAL SCORE
0
1
2
3
4
5
DAYS POST TRANSFER
0
10
20
30
40
50
60

FIG. 13.

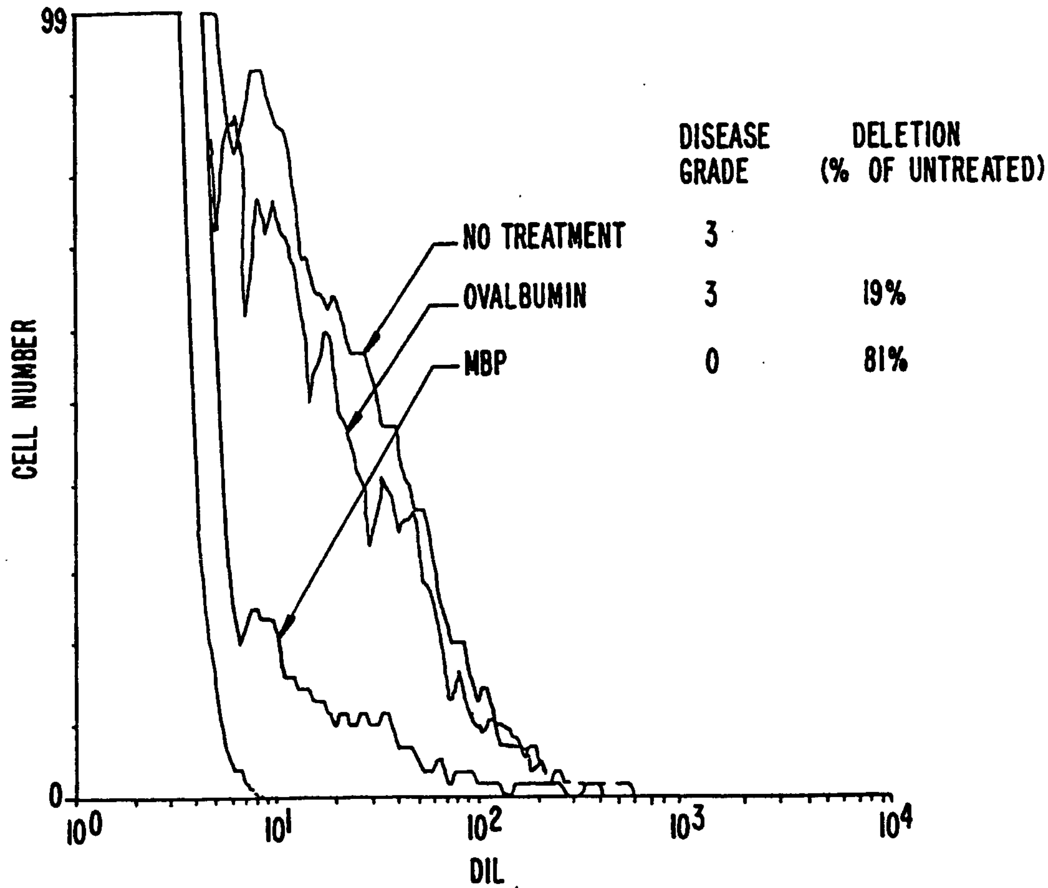

99
0
CELL NUMBER
DISEASE GRADE
DELETION (% OF UNTREATED)
NO TREATMENT 3
OVALBUMIN 3 19%
MBP 0 81%
10^0
10^1
10^2
10^3
10^4
DIL

FIG. 14.

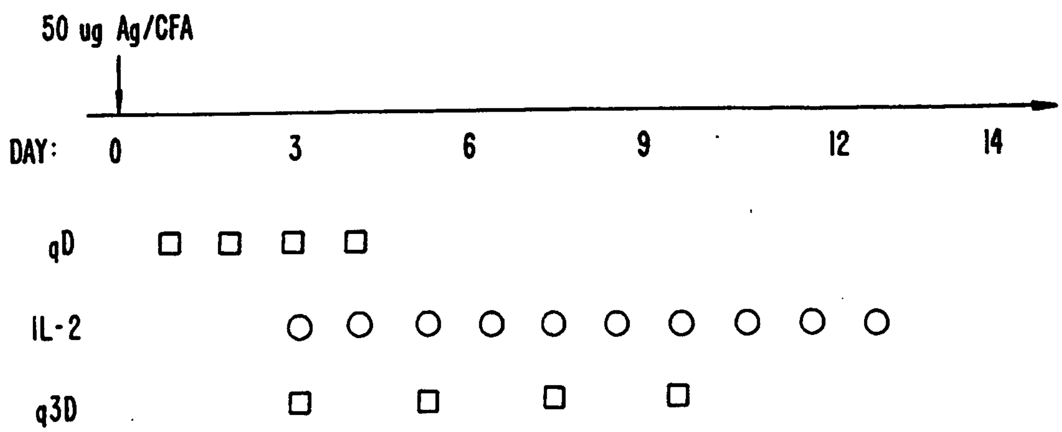

50 ug Ag/CFA
DAY: 0 3 6 9 12 14
qD
IL-2
q3D

FIG. 16.

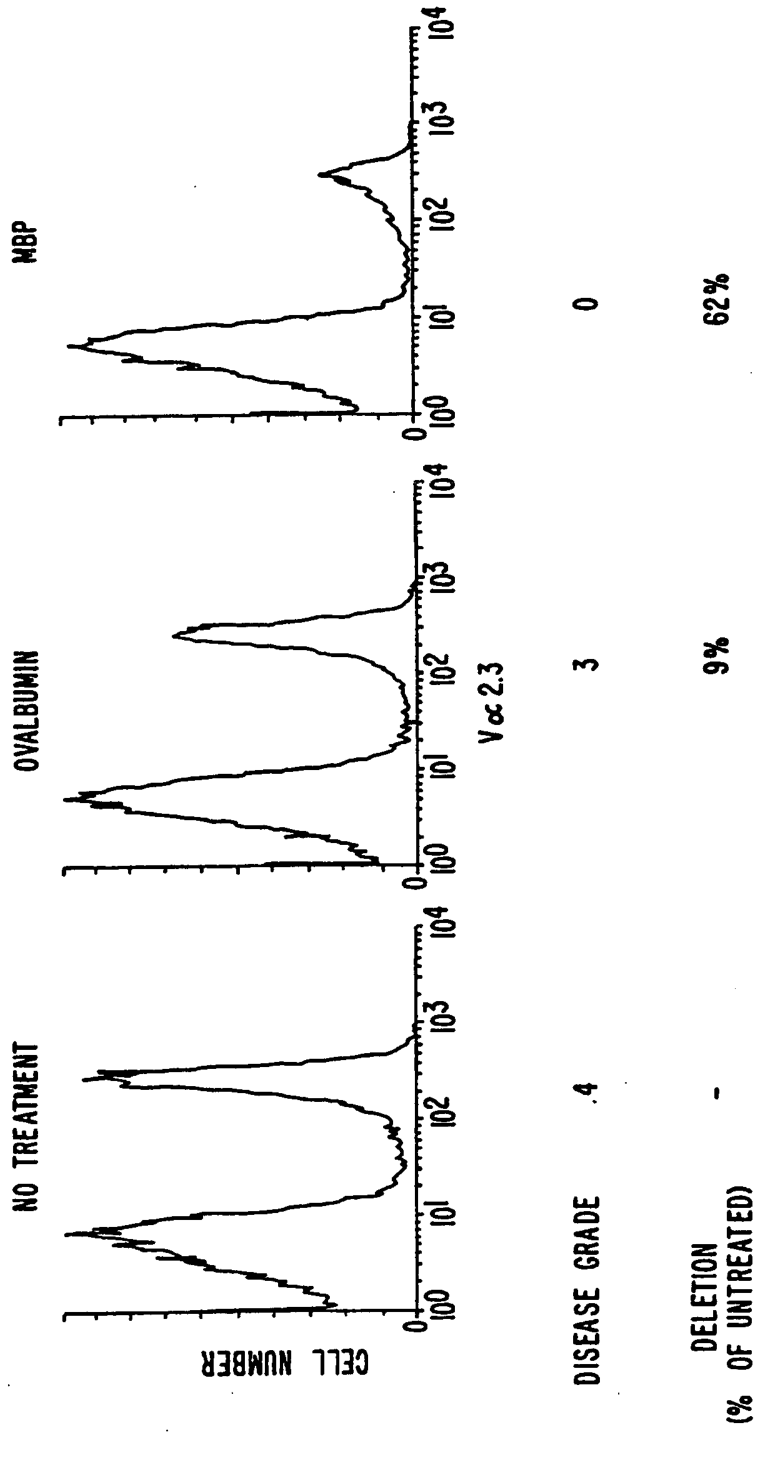

NO TREATMENT
OVALBUMIN
MBP
CELL NUMBER
0
10^0
10^1
10^2
10^3
10^4
Vα 2.3
DISEASE GRADE
4
3
0
DELETION
(% OF UNTREATED)
-
9%
62%

FIG. 15.

EXPT.	MOUSE	DISEASE	TREATMENT	OD	OS
1	1	NO INJECTION	NONE	0	0
	2	"	"	0	0
	3	"	"	0	0
	4	"	"	0	0
	5	50 ug IN CFA	NONE	2	2
	6	"	"	2	1
	7	"	"	3	2
	8	"	IL-2 ONLY	Tr	Tr
	9	"	"	2	2
	10	"	IRBP qD x 4	1	1
	11	"	"	Tr	1
	12	"	"	2	3
	13	"	"	1	1
	14	"	IRBP qD x 4 + IL-2	2	1
	15	"	"	2	1
	16	"	"	2	2
	17	"	"	Tr	1
	18	"	IRBP q3D x 4	1	0
	19	"	"	0	0
	20	"	"	1	1
	21	"	"	1	Tr
	22	"	IRBP q3D x 4 + IL-2	1	1
	23	"	"	0	0
	24	"	"	0	0
	25	"	"	0	0

FIG. 17.

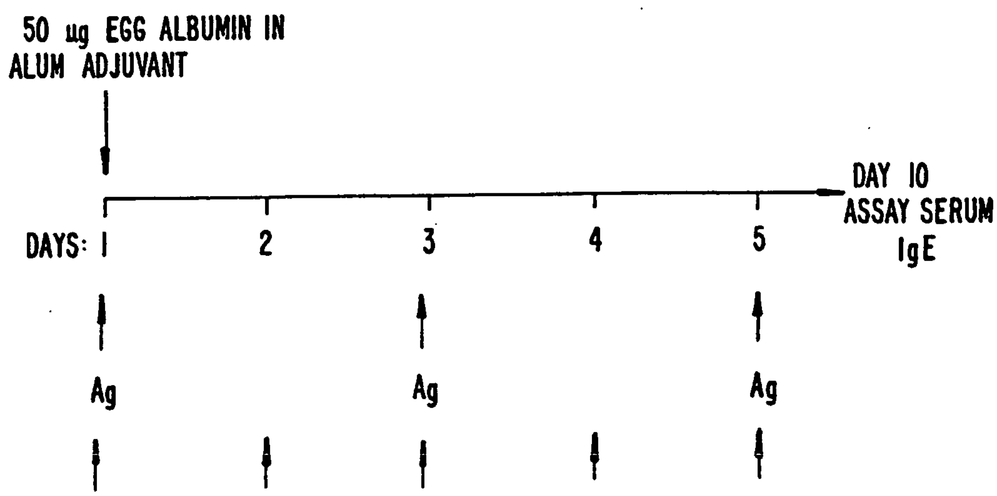


FIG. 18.

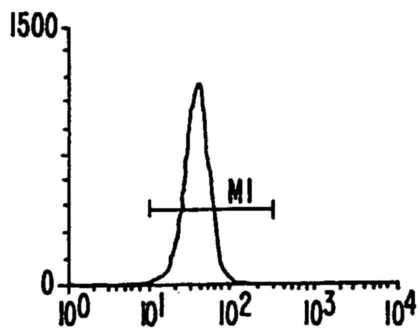


FIG. 20A.

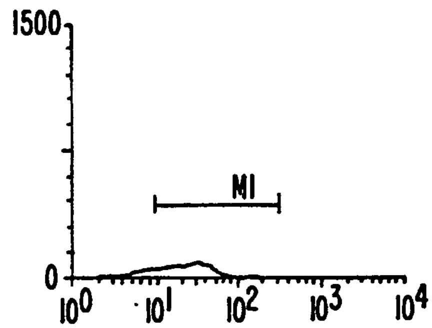


FIG. 20B.

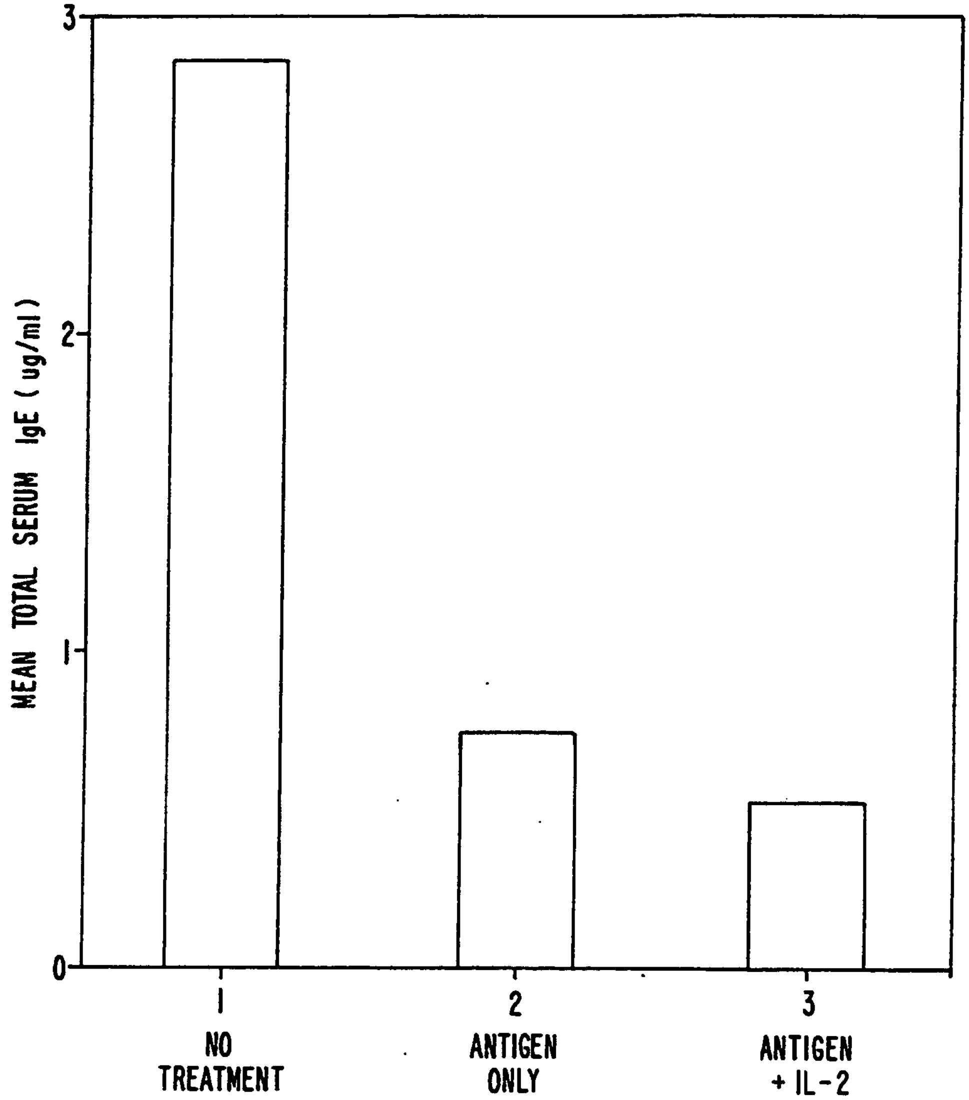

MEAN TOTAL SERUM IgE (ug/ml)
3
2
1
0
1
NO
TREATMENT
2
ANTIGEN
ONLY
3
ANTIGEN
+ IL-2

FIG. 19.

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/05481

A. CLASSIFICATION OF SUBJECT MATTER

IPC(5) :A61K 39/00, 39/35, 37/02, 45/05
US CL :424/85.1, 85.2, 88
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

U.S. : 424/85.1, 85.2, 88; 514/825, 885, 903; 530/806

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

Chem Abstracts, Medline, APS, AIDSLine, Derwent

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X Y	Cell, Volume 59, Issued 20 October 1989, D.C. Wraith et al, "Antigen Recognition in Autoimmune Encephalomyelitis and the Potential for Peptide-Mediated Immunotherapy", pages 247-255, see page 247.	1-3 4-24
Y	The Journal of Immunology, Volume 142, No. 10, Issued May 1989, D.S. Ucker et al, "Activation-Driven T Cell Death I. Requirements for De Novo Transcription and Translation and Association with Genome Fragmentation," pages 3461-3469, see page 3466.	4,5,7-11,16-24

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:
- "A" document defining the general state of the art which is not considered to be part of particular relevance
- "E" earlier document published on or after the international filing date
- "L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
- "O" document referring to an oral disclosure, use, exhibition or other means
- "P" document published prior to the international filing date but later than the priority date claimed
- "T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
- "X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
- "Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
- "&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
03 SEPTEMBER 1993	17 SEP 1993

Name and mailing address of the ISA/US	Authorized officer
Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231	JULIE KRSEK-STAPLES
Facsimile No. NOT APPLICABLE	Telephone No. (703) 308-0196

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US93/05481

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y	Cell, Volume 56, Issued 13 January 1989, J. White et al., "The Vβ-Specific Superantigen Staphylococcal Enterotoxin B: Stimulation of Mature T Cells and Clonal Deletion in Neonatal Mice", pages 27-35, see page 27.	4,5,7-11,16-24
Y	Science, Volume 253, Issued 19 July 1991, X. Paliard et al, "Evidence for the Effects of a Superantigen in Rheumatoid Arthritis", pages 325-329, see page 325.	4-24
Y	The Journal of Immunology, Volume 146, No. 1, Issued 01 January 1991, O. Janssen et al, "T Cell Receptor/CD3-Signaling Induces Death by Apoptosis in Human T Cell Receptor $\gamma\delta^{+}$ T Cells", pages 35-39, see pages 37-38.	4-24
Y	The Journal of Immunology, Volume 138, No. 1, Issued 01 July 1987, G.J. Nau et al, "Inhibition of IL 2-Driven Proliferation of Murine T Lymphocyte Clones By Supraoptimal Levels of Immobilized Anti-T Cell Receptor Monoclonal Antibody", pages 114-122, see page 114.	4-24
Y	W.E. Paul, "Fundamental Immunology", published 1989 by Raven Press (N.Y.), pages 876-878 and 898-902, see all.	5,9-11,16-20